INSTITUTE NOTES.

NOVEMBER, 1941.

Roll of Honour.

The Council deeply regrets to have to record the loss of the following member, who has made the supreme sacrifice whilst serving in His Majesty's Forces :—

Sergeant-Pilot C. W. WOOLGAR, R.A.F.
(Associate Member)
Killed on active service, September, 1941.

PRISONER OF WAR.

Dr. M. BA THI, B.Sc. (Student Member) has been reported as a Prisoner of War in Germany.

MEMBERS SERVING WITH H.M. FORCES.

The Institute has received notification of the following changes or additions to lists already published :—

S. H. Evans, Australian Imperial Forces.
R. E. Jones, A/C/U., Royal Canadian Air Force.
H. Macniven, Lieut., R.A.O.C.
G. A. Richards, Pte., I.C.
W. B. Rowntree, R.A., promoted to Lieut.-Colonel.

STUDENT'S MEDAL AND PRIZE.

The Council offers a Medal and Prize (up to the value of Five Pounds in books or instruments) for the most meritorious essay submitted by a Student Member of the Institute on one of the subjects listed below.

Entries must be received by the Secretary of the Institute not later than 31st May, 1942.

The maximum length of the essay is not specified, but in general essays should be from 4000 to 6000 words in length.

Entries must be typed, and one carbon copy must be furnished in addition to the original copy. The Council is prepared to give financial assistance to students who experience difficulty in getting their MSS. typed.

1. Palæogeographical Conditions which have Favoured Oil Accumulation.
2. The Interpretation of Geophysical Data in Terms of Geology.
3. Geochemical Methods of Prospecting.
4. Metals for Drilling Equipment.
5. Bottom Hole Testing Methods and their Interpretation.
6. Syntheses from Petroleum Gases.
7. Modern Techniques of Process Control in the Refinery.
8. Recent Methods for the Chemical Refining of Gasoline.

9. Mixed Solvent Refining.
10. The Production of Fuels alternative to
    (*a*) Gasoline, or
    (*b*) Fuel Oil.

BURGESS PRIZE.

Entries are also invited for the Burgess Prize (of value up to Five Pounds in books) for an essay dealing with one of the subjects given below. The conditions of entry for the Burgess Prize are the same as for the Student's Medal and Prize.

1. The History of the Petroleum Industry of any Producing Country (excluding U.S.A.).
2. The Price of Crude Oil.

The Council reserves the right to withhold the award of either of these prizes, or to award prizes of such lesser value as it may decide.

NEW MEMBERS.

The following elections have been made by the Council in accordance with the By-Laws, Sect. IV, para. 7.

Elections are subject to confirmation in accordance with the By-Laws, Sect. IV, paras. 9 and 10.

As Fellows.

CAMERON, William	Scotland.
MIDDLETON, Charles Roger	England.
MORTEN, Denis	,,
MORTON, Frank	Trinidad.
SHEPPARD, George	England.

As Members.

BEAN, Sidney Herbert	England.
BROWN, Harry Eugene	,,
CANTOR, Joseph	,,
GIBSON, Arthur Reginald	,,
HALL, Frederick John Spencer	,,
LAIDLAW, Ian Grant	Trinidad.

As Associate Members.

COWLES, Richard Edwin	Australia.
DARTNALL, Herbert James Ambrose	England.
DON, John Smart Aikman	,,
FORREST, Archibald John	,,
GIBSON, Harold	,,
LINNARD, Horace	,,
MORGAN, Ralph Victor	,,
SHIELS, Leo Osmonde	Australia.
WALTON, Norman Lorraine	England.

Transferred to Associate Members.

BROWN, Thomas	England.
STIBBS, Edward George	Trinidad.
de VERTEUIL, Louis Rene	,,

As Students.

BAILEY, Darrel Guy Fallen	England.
RALPH, Noël Albert	,,

CANDIDATES FOR ADMISSION.

The following have applied for admission to the Institute or transfer to another grade of membership, and in accordance with the By-Laws the proposals will not be considered until the lapse of at least one month subsequent to the issue of this *Journal*, during which any Fellow, Member or Associate Member may communicate by letter to the Secretary, for the confidential information of the Council, any particulars he may possess respecting the qualifications or suitability of any candidate.

The object of this information is to assist the Council in grading candidates according to the class of membership.

The names of the candidate's proposer and seconder are given in parentheses.

CHATTERLEY, Leslie George, Resident Engineer, Valvoline Oil Co. (*J. M. Marshall; James Smith.*)

FEATHERSTONE, Arthur James, Terminal Superintendent, Ocean Terminal, Texas Oil Co. (*R. F. Hurt; N. L. Anfilogoff.*)

WILSON, Alexander, Managing Director, British Oil & Turpentine Corporation, Ltd. (*H. W. Chetwin; J. G. Hunter.*)

Candidates for Admission as Students.

ASHFORTH, G. K., Dept. of Oil Engineering & Refining, Univ. of Birmingham.
BOESE, A. C. ,, ,, ,, ,, ,, ,,
CLAYTON, P. B. ,, ,, ,, ,, ,, ,,
DOD, G. F. ,, ,, ,, ,, ,, ,,
DRYER, S. R. C. ,, ,, ,, ,, ,, ,,
FOSTER, D. V. ,, ,, ,, ,, ,, ,,
GARRETT, P. A. ,, ,, ,, ,, ,, ,,
HICKS, A. E. ,, ,, ,, ,, ,, ,,
LINDNER, J. N. D. ,, ,, ,, ,, ,, ,,
WALL, T. G. ,, ,, ,, ,, ,, ,,
WINWARD, A. ,, ,, ,, ,, ,, ,,

All the above candidates are proposed by *Prof. A. W. Nash* and seconded by *Dr. A. H. Nissan.*

NOMINATIONS FOR COUNCIL.

Every Fellow, Member or Associate Member of the Institute may send in writing to the Council the name of a Fellow or Member whom he desires to recommend for election to the Council. This nomination must be signed by at least nine other Fellows, Members or Associate Members, and delivered to the Secretary not later than 31st December, 1941. No member may sign more than one nomination paper. Nomination papers may be obtained from the Secretary.

ARTHUR W. EASTLAKE,
Honorary Secretary.

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Vol. 27. No. 215. November 1941.

HYDROCARBON SOLVENTS FROM PETROLEUM AND THEIR INDUSTRIAL APPLICATIONS.*

By F. N. Harrap, M.Sc., and E. B. Evans, Ph.D., M.Sc.

The industrial uses of petroleum products are many and varied, quite apart from their uses as fuels and lubricants. A range of solvents of varying volatilities is an important contribution of the petroleum industry to many manufacturing processes. There is a quite extensive literature on solvents generally, but there does not appear to be any comprehensive discussion on the properties and applications of the petroleum solvents, although numerous papers deal with specific properties and many books describe the uses of these materials in individual processes.

This paper does not attempt to go very deeply into the subject, but merely to give a general description of the commonly available petroleum solvents and the way in which they are used. It is felt that this treatment may be of some interest and use both to the petroleum technologist and to the users of such solvents.

Before the war, a very large variety of petroleum spirits was available for industrial use. Many of these differed only slightly from the main types and were made to suit the individual convenience of users. Nowadays, however, some of the special raw materials are no longer available, and it is in the interests of conservation of supplies to reduce the number of grades made to the main types. The chief solvents now available comprise a range of six Special Boiling-Point Spirits (S.B.P.'s Nos. 1 to 6), Pool Rubber Solvent (R.S.), Pool White Spirit and Pool Distillate. In addition, kerosine and vaporizing oil find some application as solvents. This range of materials has proved in practice adequate for the basic needs of industry and fulfils most of the purposes for which such distillates were employed before the war.

The Manufacture of Petroleum Solvents.

The light-petroleum solvents are manufactured by distillation from specially selected and refined naphthas. The products are usually subjected to chemical treatment to remove traces of sulphur compounds and improve odour. A brief description of the distillation processes is given below.

The S.B.P.'s and rubber solvent are usually produced in batch-stills, as this is found more convenient on account of the overlapping distillation ranges of the products required. It is possible, however, to produce these spirits from a continuous unit, taking off several sidestreams and combining suitably. White spirit is more often made in a continuous unit, as one definite main product is required from the operation.

Typical batch-stills consist of cylindrical shells about 24 feet in length and 9 feet in diameter, accommodating a charge of approximately 7,000 to 8,000 gallons. The stills are well lagged and provided with closed steam coils

* Paper presented to a Meeting of the Institute in London on Tuesday, 10th June, 1941.

(at about 140 lb./sq. in.) and open coils (at about 15 lb./sq. in.). Heating by the circulation of hot oil through the coils provides a modern alternative to the method of using closed steam. The open steam is required for the distillation of heavier fractions in order to speed up the process and avoid decomposition. Heat input to the still is automatically controlled. Each still is provided with a fractionating column about 36 feet high and 3 feet diameter. This may either be packed with rings or some other suitable filling or contain, say, twenty trays with bubble-caps, to promote good contact between the ascending vapour and the liquid reflux. The overhead vapour from the column is condensed in a tubular condenser, from which it passes to a reflux drum. From the latter a portion of the condensate is pumped back to the top of the column to

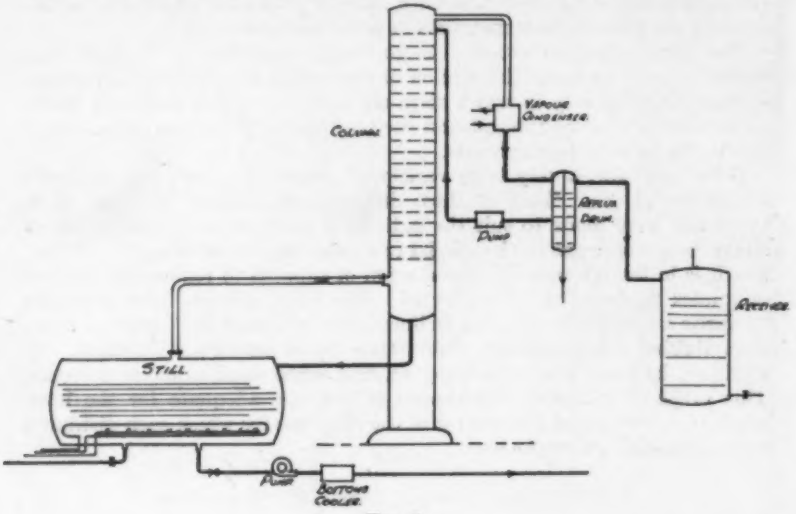


Fig. 1.

BATCH STILL.

provide the necessary reflux for fractionation. The reflux drum, which may be about 6 feet high by 2 feet diameter, also separates the condensed water from the spirit fraction.

A number of stills, say from three to eight, is grouped in a battery and provided with a series of product receiving tanks, into which suitable fractions from the various stills can be run and accumulated.

Suitably placed thermometers, flowmeters, and control valves enable the rate of distillation, proportion of reflux, and disposal of products to be controlled, mainly from a control panel.

The detailed procedure adopted for a run will depend on the properties of the naphtha being distilled, the characteristics of the plant, and the specifications of the products required. The best operating conditions are worked out by experiment. More or less blending of fractions and re-distillation will be required to enable the final specifications to be met.

A complete run, in a still of type described above, including cooling down and re-charging, will take approximately 50 hours. There is inevitably a distillation loss in processing these light naphthas, and this may amount to some 3 per cent. of the material charged. 1 or 2 per cent. of the charge is also left as heavy bottoms, and this is run off and stored pending re-working to some heavier grade or other means of disposal.

White spirits are very conveniently made in a continuous distillation unit, although batch-stills are often used. In the continuous process a suitable rough cut from the distillation of a crude petroleum is pumped through heat exchangers to the fractionating column. The column may be some 60 to 70 feet high and 3 feet in diameter, containing about thirty plates with bubble-caps. The incoming white spirit enters near the bottom

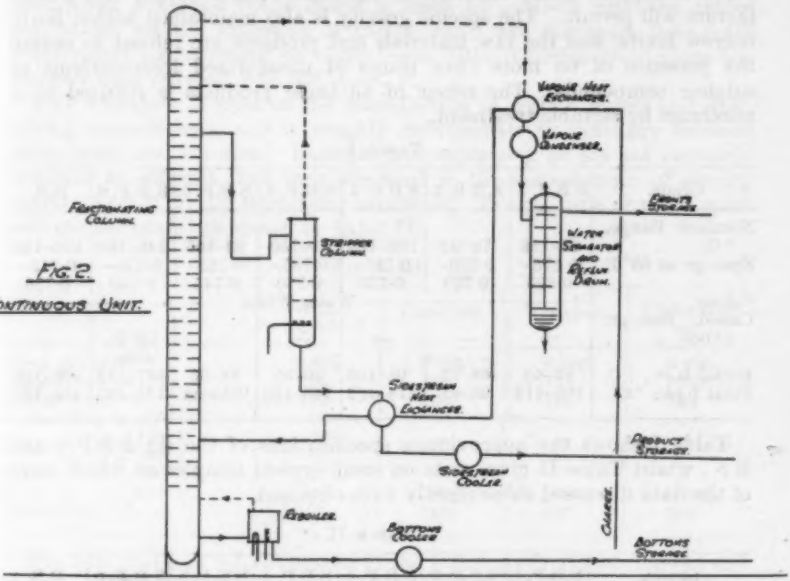


FIG. 2.
CONTINUOUS UNIT.

of the column, but not necessarily at the lowest plate. At the base of the column is a " re-boiler " heated with closed steam at 140 lb./sq. in. and open steam at about 15 lb./sq. in. This steam provides the heat necessary to vaporize the incoming crude white spirit. Steam and light fractions (fronts) are taken off overhead from the column, whilst the main fraction of white spirit is run off as a sidestream from a suitable plate in the column. The heavy fractions of the feed-stock collect in the re-boiler, from which they are continuously run off through a cooler to storage.

The fronts and steam are taken through heat-exchangers to a condenser and thence to a water-separator. From this a portion of the condensate is returned to the top plate of the column to act as reflux. The main white spirit fraction flows to a small " stripper column," where, by the action of live steam, a final control is obtained on the initial boiling point

and flash-point of the product. The main product passes through coolers to storage, where it is held pending final chemical treatment, whilst the overheads from the stripper are returned to the main fractionation column at a point above that at which the main sidestream was taken off.

The Specifications and Properties of Petroleum Solvents.

1. *Specifications.*

The special boiling-point spirits and rubber solvent are cut to specified distillation ranges, since controlled volatility is their most important property. The percentages distilling at temperatures intermediate to the initial and final boiling points cannot be guaranteed, but the volatility curve is kept as nearly constant as the conditions of supply and manufacture will permit. The specific gravity is also maintained within fairly narrow limits, and the raw materials and products are refined to ensure the presence of no more than traces of unsaturated hydrocarbons or sulphur compounds. The odour of all these products is reduced to a minimum by suitable treatment.

Table I.

Grade.	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	R.S.
Nominal Range, ° C.	35–115	70–95	100–120	40–150	90–105	140–160	100–160
Spec. gr. at 60° F.	0·675–0·695	0·700–0·720	0·735–0·755	0·705–0·730	0·725–0·745	0·770–0·790	0·745–0·770
Colour	Water White						
Closed flash-pt. (Abel)	—	—	—	—	—	73° F. min.	—
Initial b.pt., ° C.	35–45	68–72	98–105	30–50	88–95	137–143	100–120
Final b.pt., ° C..	100–115	90–95	118–122	140–160	105 max.	155–165	155–165

Table I shows the approximate specifications of the six S.B.P.'s and R.S., whilst Table II gives tests on some typical samples on which some of the data discussed subsequently were obtained.

Table II.

Grade.	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	R.S.
Spec. gr. at 60° F.	0·685	0·711	0·745	0·717	0·729	0·780	0·757
Distillation (° C.):							
Initial b.pt.	43	68	101	48	89	141	113
2% at	51	69	102½	52	89½	141½	114
10% at	55	71	103	61½	90½	142	115½
20% at	58	71½	103½	67½	91	143½	116
40% at	64	73½	105	81	92	144½	119
50% at	67	74½	105½	88	93	145½	121
60% at	70	76	106	95	93½	146½	123
80% at	80	80	109	112	95	150	129
90% at	89½	84½	112	126	96½	155½	138½
95% at	98	89	116	136	99	160	146
Final b.pt., ° C.	105	95	121	149	103	165	157
Recovery	97%	98%	98½%	97½%	98%	98%	97%
Residue	1%	1%	1%	1%	1%	1%	1%
Closed flash-pt.	—	—	—	—	—	74° F.	—

It must be mentioned here that all distillation figures quoted are by the standard Institute of Petroleum method. Some users carry out tests with fractionating columns of various types and using flasks of different sizes, oil-bath heating, and similar modifications. The results of such tests are not comparable with the standard figures, on account of the different degrees of fractionation obtained, larger hold-up in the column, etc.; the loss and residue figures obtained may vary widely, according to the method used.

Pool White Spirit conforms to the B.S.I. Specification No. 245 of 1936, as recently modified to meet emergency conditions. The "Freedom from Corrosive Properties" clause now provides that a polished copper strip shall not be discoloured or pitted when heated in the spirit at 100° C. for 3 hours. The B.S.I. Specification calls for 78° F. minimum Abel flash-point, but Pool White Spirit is made to conform with the export regulations for the shipment of paints, etc.; the minimum flash-point requirement for shipment on cargo-boats without undue restrictions has recently been reduced from 93° to 88° F.

Pool Distillate is used in the manufacture of certain paints and slow-drying compositions, and is roughly intermediate in volatility between white spirit and kerosine. Kerosine and vaporizing oil are not primarily designed as solvents, but they are used in the manufacture of stoving enamels and in certain degreasing processes. Typical tests of white spirit and the kerosines are shown in Table III.

TABLE III.

	White spirit.	Distillate.	Kerosine.	Vaporizing oil.
Spec. gr. at 60° F.	0·801	0·795	0·800	0·830
Closed flash-pt., ° F.	94	104	115	95
Initial b.pt., ° C.	149	150	160	145
Distilling to 160° C.	40%	—	—	—
„ „ 170° C.	72%	—	—	—
„ „ 180° C.	88%	—	—	—
„ „ 190° C.	97%	—	—	—
„ „ 200° C.	—	60%	38%	55%
Final b.pt., ° C.	195	280	285	265

The two grades of solvent known in the U.S.A. as Stoddard Solvent and Petroleum Spirits (Mineral spirits) are roughly equivalent to Pool White Spirit. The specifications are laid down by the A.S.T.M. (Report of Committee D.2, 1940) and are briefly as follows:

TABLE IV.

Grade.	Stoddard solvent.	Petroleum spirits.
Specification No.	D 484–40	D 235–39
Flash-pt. (Tag-closed)	100° F. min.	100° F. min.
Distillation:		
176° C.	50% min.	50% min.
190° C.	90% min.	—
Final b.pt.	210° C. max.	210° C. max.
Corrosion (copper strip)	Only slight discoloration after 3 hrs. at 212° F.	No marked blackening after 30 mins. at boiling point of spirit.

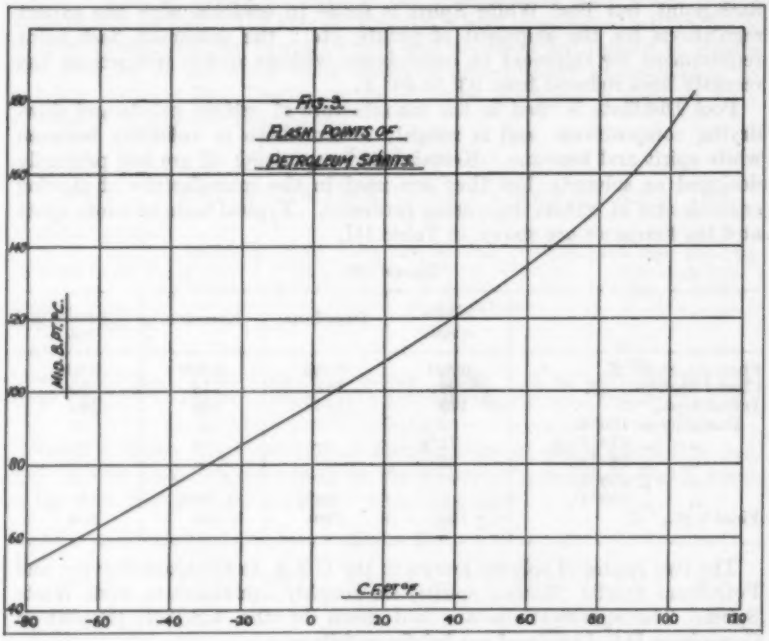
"Stoddard Solvent" is used for dry-cleaning and "Petroleum Spirits" is intended for the paint and varnish industries.

The product known as V.M. & P. (varnish makers' and painters') naphtha generally has a boiling range of approximately 100 to 155° C. and is equivalent to Pool Rubber Solvent.

2. *Properties.*

(i) *Flash-point and Inflammability.*

Petroleum vapours, if mixed with air in proportions varying between certain limits, will ignite or explode on the application of a flame or



electric spark. The conditions in which this occurs are dependent on a number of factors, such as temperature, ventilation, the nature of the space in which the air-vapour mixture is formed, the intensity of the spark, and so on. It is necessary to distinguish between the properties of a liquid which determine the ease with which it gives off sufficient vapour to form an explosive mixture with air under certain conditions and the inflammable properties of the vapour so formed.

Considering first the liquid, the usual criterion for its readiness to give off vapour is the "flash-point"—*i.e.*, the temperature at which the liquid will give off sufficient vapour to flash on the application of a flame under arbitrarily selected conditions in a standard apparatus. This figure, the

lower flash-point, is obtained by a procedure involving gradual raising of the temperature, and is dependent to a large extent on the proportion and nature of the lightest constituents present. In the case of narrow-cut fractions there seems to be a fairly close relation between the volatility (measured by the 50 per cent. distillation temperature) and the Abel flash-point. Such a relation is illustrated in Fig. 3, and from this the approximate flash-points of the S.B.P.'s, rubber solvent, and white spirit samples referred to above would be approximately :

TABLE V.

	Flash-point, ° F.	Temperature at which 50% is distilled, ° C.
S.B.P. No. 1	− 54	67
„ „ 2	− 40	74½
„ „ 3	+ 15	105½
„ „ 5	− 7	93
„ „ 6	+ 74	145½
Rubber solvent . . .	+ 40	121
White spirit	+ 93	163

It will be noted that the estimated flash-point of S.B.P. No. 4 is not given above. The 50 per cent. point is only an approximate guide to the ease of formation of vapour in the case of the narrow fractions. S.B.P. No. 4 boils over a wide range, and a better estimate of its flash-point would be obtained from the vapour pressure rather than from the mean volatility. (The 50 per cent. point of S.B.P. No. 4 is 88° C.) Plotting Reid vapour pressures at 100° F. against flash-point, and interpolating for S.B.P. No. 4, leads to a value of approximately − 48° F. for this solvent.

It may be of interest to mention here the relationships stated by Ormandy and Craven (*J. Inst. Petrol. Tech.*, 1922, **8**, 163) for the flash-points of hydrocarbons. These authors found that the vapour pressures of all hydrocarbons at their flash-points are approximately the same—viz., 12 mm. Hg (0·232 lb./sq. in.) for the lower and 40–50 mm. Hg (0·967 lb./sq. in.) for the higher flash-point. They found also that the lower flash-point in ° abs. is approximately equal to 0·736 × boiling point in ° abs.

S.B.P. No. 6 is the only one of the light solvents which flashes above 73° F., and it is expressly designed to have the maximum volatility consistent with such a flash-point, which confers freedom from the provisions of certain petroleum storage regulations. White spirit flashes above 88° F. (usually above 90° F.), whilst kerosine and Distillate flash above 100° F. and vaporizing oil about 95° F. Flash-point and vapour pressure (*q.v.*) give some indication of the tendency of petroleum products to give off inflammable vapour, but the vapours themselves differ in their limiting concentrations for, and ease of, inflammability.

An explosive or inflammable mixture may be defined as one in which flame can be propagated independently and away from the original source of ignition. It is only between the concentrations represented by the upper and lower limits of inflammability that self-propagation of the

flame will take place after ignition has been effected. Combustion may occur over wider limits with a continuous application of flame.

The explosive limits for petroleum-spirit vapours are usually taken as about 1·2–6 per cent. vol. in air, but the conditions influence the results widely. Thus, the explosive range is usually less in large vessels, and varies also with the direction of the propagation of flame, location of the source of ignition, intensity of igniting spark, etc. The lower-molecular-weight hydrocarbons have a wider explosive range (cf. Wheeler, *J.C.S.*, 1924, **125**, 1858).

The following estimated figures give some idea of the explosive ranges for some of the solvent vapours under working conditions:

TABLE VI

Grade.	Vol. % vapour in air.	
	Lower limit.	Upper limit.
S.B.P. No. 1	1·3	7·2
„ „ 2	1·25	7·0
„ „ 3	1·1	6·7
„ „ 4	1·2	6·8
„ „ 5	1·2	6·8
„ „ 6	1·0	6·3
Rubber solvent	1·1	6·5
White spirit	1·0	6·2

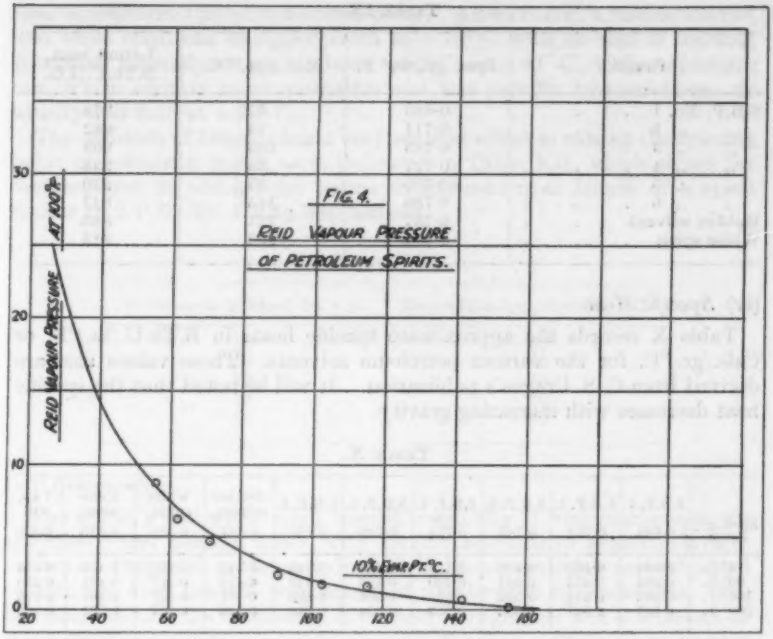
(ii) *Vapour Pressure.*

The vapour pressure of a solvent influences to a considerable extent its inflammability and also its behaviour on evaporation. The lighter fractions have the greatest effect on vapour pressure, and the property increases quite rapidly with temperature. Table VII illustrates the variation in vapour pressure in lb./sq. in. for some of the products for which typical tests are given in Tables II and III. The Reid vapour-pressure bomb was employed for these determinations.

TABLE VII.

Temp. ° F.	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	Rubber solvent.	White spirit.
40	2·0	0·8	—	1·4	—	—	—	—
60	3·2	1·3	—	2·2	—	—	—	—
80	4·7	2·8	0·5	3·8	0·8	—	0·3	—
100	8·7	4·6	1·8	6·2	2·3	0·6	1·6	0·15
120	—	—	4·7	—	5·4	1·7	3·7	1·0
140	—	—	—	—	—	3·6	—	3·0

There is a fairly good relationship between the 10 per cent. evaporated distillation point of light-petroleum solvents (*e.g.*, S.B.P.'s and normal gasolines) and their Reid vapour pressures at 100° F., and this is illustrated in Fig. 4.



(iii) *Latent Heats of Vaporization.*

The latent heats of petroleum products vary considerably with the temperature of evaporation. The value in B.Th.U. per lb. is inversely proportional to the density of the product, so that the latent heat of a gallon of petroleum depends only on the temperature of vaporization.

In Table VIII are recorded the latent heats in B.Th.U./Imp. gallon for a gallon of petroleum product vaporized at various temperatures. Values in B.Th.U./lb. are easily obtained using the known gravities at 60° F. of the particular solvent concerned. These are approximate average figures, and are derived from C. S. Cragoe, "Thermal Properties of Petroleum Products," U.S.B.M. Miscellaneous Publication No. 97, 1929.

TABLE VIII.

Temperature		Latent heat vaporisation, B.Th.U./Imp. gallon, 60° F.
° F.	° C.	
60	15·5	1055
100	38	1022
200	93	930
300	149	840
400	204	750

For the Pool S.B.P.'s and White Spirit at their mid-boiling points the approximate values will be :

TABLE IX.

Grade.	Spec. gr., 60° F.	Mid-b.pt. ° C.	Latent heat, B.Th.U./I.G.
S.B.P. No. 1 . . .	0·685	67	973
„ „ 2 . . .	0·711	74	962
„ „ 3 . . .	0·745	105	908
„ „ 4 . . .	0·717	88	938
„ „ 5 . . .	0·730	93	930
„ „ 6 . . .	0·780	145	847
Rubber solvent . .	0·757	121	885
White spirit . . .	0·801	163	815

(iv) *Specific Heat.*

Table X records the approximate specific heats in B.Th.U./lb./°F. or Cals./gr./°C. for the various petroleum solvents. These values also are derived from C. S. Cragoe's publication. It will be noted that the specific heat decreases with increasing gravity.

TABLE X.

	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	Rubber solvent.	White spirit.	Kero-sine.	Vap. Oil
Spec. gr., 60° F.	0·685	0·711	0·745	0·717	0·730	0·780	0·757	0·801	0·810	0·830
0° F.	0·469	0·460	0·450	0·458	0·453	0·440	0·446	0·437	0·429	0·424
60° F.	0·501	0·492	0·481	0·490	0·484	0·470	0·476	0·467	0·461	0·456
100° F.	0·523	0·514	0·502	0·511	0·506	0·490	0·497	0·487	0·481	0·476
200° F.	0·577	0·567	0·553	0·563	0·554	0·540	0·548	0·537	0·531	0·525

(v) *Viscosity.*

The petroleum solvents have low viscosities, which for spirits of similar origin increase with the densities and boiling ranges. Typical figures are shown in Table XI, the results being expressed in centistokes.

TABLE XI.

Grade.	Spec. gr., 60° F.	Boiling range, °C.	Viscosity in cs. 0° C.	Viscosity in cs. 20° C.
S.B.P. No. 1 . .	0·6865	35–115	0·617	0·510
„ „ 2 . .	0·7215	70–95	0·776	0·629
„ „ 3 . .	0·7470	100–120	0·916	0·717
„ „ 4 . .	0·7160	40–150	0·732	0·598
„ „ 5 . .	0·7380	90–105	0·853	0·679
„ „ 6 . .	0·7735	140–160	1·347	1·017
Rubber solvent . .	0·7690	100–160	1·132	0·884

White spirits and kerosines are rather more viscous, the former being approximately 1·4 cs. at 20° C., whilst typical figures for kerosine are 2·9 cs. at 0° C. and 1·9 cs. at 20° C.

(vi) *Freezing Point.*

Normal petroleum spirits have very low freezing points, and with low benzene contents figures of down to −120° C. have been found. At

this temperature the spirit becomes pasty. All six S.B.P.'s, rubber solvent, and white spirit can be cooled down to —70° C. with no sign of freezing. Kerosines normally set-up at about —50° C. to —60° C., while vaporizing oils, which contain more aromatics and less paraffin hydrocarbons, are usually still fluid at —70° C.

The addition of benzole has a very marked effect in raising the freezing point of petroleum spirit, as is indicated in Table XII, which shows the temperatures at which solid begins to separate from blends of a spirit similar to S.P.B. No. 4 with 90s. benzole.

TABLE XII.

% Benzole in blend by vol.	Separation temperature, ° C.
15	— 50
20	— 45
30	— 35
40	— 30
50	— 25

(vii) *Composition.*

The S.B.P.'s and white spirit consist essentially of hydrocarbons of the naphthene and paraffin series, with smaller amounts of aromatic hydrocarbons. Prepared, as they are, from straight-run materials and subjected to refining, they contain only traces of unsaturated hydrocarbons. For the same reason, the total sulphur content is negligible and deleterious or corrosive sulphur compounds are absent. Benzene is likely to be present only in quite small quantities, *e.g.*, in S.B.P.'s 1, 2, 4, and, possibly, S.B.P. 5. In no case can the percentage present exceed a few per cent., and this fact is of importance in relation to the "Fume Process" regulations. Toluene, ethylbenzene, and the xylenes are present in the higher-boiling members of the series.

TABLE XIII.

Hydrocarbon Composition of Petroleum Solvents (Per Cent. Weight).

	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	Rubber solvent.	White spirit.	Kerosine.	Vap. oil.
Aromatics .	3·0	4·5	10·5	5·0	4·5	17·5	12·0	19·0	11·0	21·0
Naphthenes.	18·0	30·0	40·0	35·0	44·5	38·0	27·5	51·5	17·5	41·5
Unsaturateds	0·5	0·5	0·5	0·5	0·5	1·0	1·0	0·5	2·5	2·5
Paraffins .	78·5	65·0	49·0	59·5	50·5	43·5	49·5	29·0	69·0	35·0

The hydrocarbon analyses quoted in Table XIII must be regarded as approximations only. Considerable variation may occur according to the origin of the products.

(viii) *Solvent Power.*

(a) *Oils and Fats.*—Petroleum spirits are excellent solvents for practically all the animal and vegetable oils and fats, including wool-fat.

An exception is castor oil, which, by reason of its hydroxylated nature, is soluble only to a very limited extent in most petroleum solvents.

(b) *Paraffin Wax.*—Here the solubility depends largely on the temperature, the composition of the solvent, and the nature of the wax. The method of determination of the solubility may also have some bearing on the results.

In Tables XIV and XV an indication of the solubility of wax at 15° C. and 25° C. is given by the results on American 122–5° F. m.pt. wax.

TABLE XIV.

Solubilities American 122–5 Wax.

(Gm. wax/100 mls. solution.)

Temp., ° C.	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	Rubber solvent.	White spirit.
15	14·1	12·3	9·7	13·5	9·7	9·2	9·6	8·9
25	24·1	23·8	23·0	23·6	22·8	22·3	22·5	20·1

TABLE XV.

Solubilities American 122–5 Wax.

(Gm. wax/100 gm. solution.)

Temp. ° C.	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	Rubber solvent.	White spirit.
15	20·6	18·1	13·8	19·8	14·2	12·9	13·2	12·0
25	32·5	31·5	30·2	31·1	29·8	28·6	29·0	26·3

The influence of temperature on wax solubility is much greater than the variations between the different solvents in this respect. There is a rough relation between the mean volatility of solvents of similar origin and their solvent power for wax (Fig. 5).

(c) *Rubber.*—When raw rubber is immersed in petroleum spirit, it swells considerably, due to absorption of the solvent. When mechanical action, such as stirring or shaking, is applied, the swollen mass disperses through the unabsorbed solvent forming a colloidal "solution." If rubber has been masticated (*i.e.*, subjected to mechanical action leading to partial breakdown of the rubber structure) it yields solutions which are of lower viscosity than those of unmasticated rubber in the same concentration and the same solvent.

The presence of aromatics, and to some extent naphthenes, increases the solvent power of spirits for rubber.

Vulcanized rubber also swells to some extent when immersed in petroleum spirit, but mechanical action or heat does not disperse the rubber into colloidal solution.

Chlorinated rubbers are not soluble in petroleum spirits unless a large proportion of aromatic hydrocarbons is present.

Petroleum solvents have to a large extent displaced benzene and other coal-tar hydrocarbons as rubber solvents, on account of the lower toxicity of the former.

Rubber solutions, as used in industry, may contain 6–12 per cent. or more of rubber, in one of the S.B.P.'s or rubber solvent.

(d) *Resins.*—Jordan ("The Technology of Solvents") relates resin solubility with oxygen content. The oxygen-containing types, such as shellac, copal, phenolformaldehyde, and urea-formaldehyde resins, are completely insoluble in hydrocarbons. Those resins which are free from or have low oxygen contents—*e.g.*, rosin esters, coumarone resins, and *cyclo*hexane resins—have a limited solubility in petroleum spirits. Some resins of the phthalic acid (alkyd) type are fairly readily soluble in petroleum. Urea-formaldehyde resins soluble in white spirit have recently been introduced (cf. Worsdall, "O. & C. T. J.," 1940, p. 848).

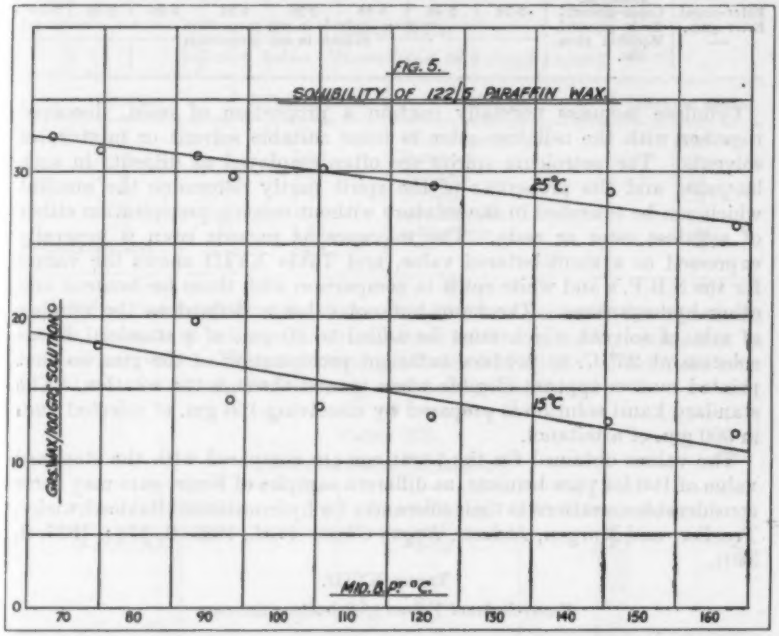


Table XVI is extracted from Jordan, and shows the solubility of a few resins; it refers to mixtures of equal parts of resin and solvent at room temperature.

TABLE XVI.

Elemi *	Dammar ‡
Rosin ‡	Ester Gum *
Gallipot *	Albertol *
Mastic †	Alkydal *
Kauri Copal †	Polystyrol †

* Soluble.
† Insoluble.
‡ Partially soluble.

The results of some determinations of the solubility of a few gums are

given in Table XVII, and indicate, as does Table XVI, the very wide variations which exist.

TABLE XVII.

Solubilities of Some Resins.

(Gm./100 gm. solution.)

Gum.	Type.	S.B.P. 1.	S.B.P. 2.	S.B.P. 3.	S.B.P. 4.	S.B.P. 5.	S.B.P. 6.	Rubber solvent.	White spirit.
Kauri.	Natural.	Not appreciably soluble							
Bakelite.	Straight phenol-aldehyde.	0·06	0·07	0·10	0·075	0·07	0·13	0·12	0·16
Ester-copal.	Copal-glycerol.	3·16	3·46	3·48	3·20	3·24	3·36	3·65	3·78
Ester-gum.	Rosin-glycerol.	Soluble in any proportion							
—	Modified phenolic.	Soluble in any proportion							

Cellulose lacquers normally contain a proportion of resin, dissolved together with the cellulose ester in some suitable solvent or mixture of solvents. The petroleum spirits are often employed as diluents in such lacquers, and the properties of the spirit partly determine the amount which can be tolerated in the mixture without causing precipitation either of cellulose ester or resin. The tolerance as regards resin is generally expressed as a kauri-butanol value, and Table XVIII shows the values for the S.B.P.'s and white spirit in comparison with those for benzene and other hydrocarbons. The kauri-butanol value is defined as the number of mls. of solvent which must be added to 20 gm. of a standard Kauri solution at 25° C. to produce sufficient precipitation of the gum so that printed matter appears illegible when viewed through the solution. The standard kauri solution is prepared by dissolving 100 gm. of selected gum in 500 gm. of *n*-butanol.

The values obtained for the titrations are compared with the standard value of 100 for pure benzene, as different samples of Kauri gum may show considerable variations in their tolerances for hydrocarbons (Baldeschwieler, Troeller, and Morgan, *Industr. Engng Chem. Anal.*, 1935, **9**, 374; 1937, **9**, 540).

TABLE XVIII.

Kauri-Butanol Values of Petroleum Solvents.

Grade.	Kauri-butanol value.	Grade.	Kauri-butanol value.
S.B.P. No. 1 . .	27·5	White spirit . .	41·5
,, ,, 2 . .	31·9	Benzene . . .	100·0
,, ,, 3 . .	33·3	Toluene . . .	91·9
,, ,, 4 . .	29·4	Xylenes . . .	85·3
,, ,, 5 . .	31·1	*cyclo*Hexane . .	54·0
,, ,, 6 . .	35·4	*n*-Heptane . .	24·8
Rubber solvent . .	37·4		

(e) *Cellulose Esters.* Cellulose esters are not soluble in petroleum or other hydrocarbons, but a certain amount of petroleum spirit is tolerated by solutions of cellulose in the more expensive alcohols, ketones, and esters. Larger amounts of aromatic hydrocarbons can be tolerated than of paraffins, whilst naphthenes show intermediate results. Nitrocellulose

solutions will tolerate more petroleum spirit than will cellulose acetate solutions in the same concentration in the same solvent.

The tolerance is usually expressed in terms of "dilution ratio"—*i.e.*, the ratio of diluent to solvent necessary to produce permanent turbidity when the diluent is added gradually with shaking to a solution of 10 gm. ½ sec. nitrocellulose in 50 mls. *n*-butyl acetate, the titration being carried out at 20° C. Thus:

$$\text{Dilution Ratio} = \frac{\text{mls. Diluent to produce turbidity}}{50}.$$

TABLE XIX.

Dilution Ratios (Nitrocellulose in n-Butyl Acetate).

Grade.	Dilution ratio.	Grade.	Dilution ratio.
S.B.P. No. 1	1·22	White spirit	1·24
„ „ 2	1·20	Benzene	2·90
„ „ 3	1·21	Toluene	2·84
„ „ 4	1·17	Xylene	2·76
„ „ 5	1·18	*cyclo*Hexane	1·46
„ „ 6	1·20	*n*-Heptane	1·00
Rubber solvent	1·22		

Cellulose acetate solutions have far smaller tolerances for petroleum spirits than have nitrocellulose solutions of the same concentration in the same solvent. Thus, considering solutions of 10 gm. of cellulose ester in 100 ml. of acetone, the following comparison is obtained:

TABLE XX.

Dilution Ratios (in Acetone).

Diluent.	Nitrocellulose.	Cellulose acetate.
S.B.P. No. 1	9·15	0·92
„ „ 2	—	1·10
„ „ 3	9·9	1·12
„ „ 4	9·0	1·00
„ „ 5	—	1·10
„ „ 6	—	1·18
Rubber solvent	10·9	1·18
White spirit	11·25	1·3
Benzene	62·5	5·8
n-Heptane	5·0	0·8

The smaller concentration of 10 gm. in 100 ml. solvent is used here on account of the high viscosity of cellulose acetate solutions. It will be noted that the variation in dilution ratio over the range of petroleum solvents is not large.

(ix) *Physiological Action.*

Petroleum distillates have much less physiological action than have many other solvents. One of the most noticeable effects is the removal of fatty matter from the skin by solvent action. This leads to drying and

cracking of the skin and, if not treated, dirt and bacteria enter the pores, and inflammation is set up. This is easily prevented by cleanliness, and by regular treatment, with lanoline or a mixture of one part of lanoline with two parts pure olive oil, of the parts which come in contact with solvents during work. Treatment with antiseptic solutions is also recommended (Home Office Forms 3674, 1863 (1928); 296 and 397 (1932). The sensitivity of the skin to petroleum solvents varies greatly with the individual.

Inhalation of petroleum vapours in small quantities is comparatively harmless, and the worker soon gets accustomed to, and able to tolerate, small concentrations without discomfort. Larger quantities may produce headaches, dizziness, and nausea as the concentration increases, but recovery is rapid when the patient is transferred to the fresh air.

Henderson and Haggard ("Noxious Gases") quote the following figures as an indication of the concentrations of petroleum vapour to produce marked physiological effects:

Least detectable odour	0·03 per cent. vol.
Dangerous for even short exposure . . .	1·1–2·2 per cent. vol.
Rapidly fatal for short exposure . . .	2·4 per cent. vol. and upwards.

As regards toxicity, the paraffin hydrocarbons have very little effect, whilst the naphthenes have perhaps a little more. These two classes of hydrocarbons are those mainly present in the petroleum solvents considered.

The small amount of aromatic hydrocarbons present have a somewhat greater effect, but as the concentration is small, the light petroleum solvents may be considered as innocuous. Considering the pure aromatic hydrocarbons, benzene is usually regarded as being rather more toxic than toluene or the higher aromatics, probably due in part to its higher volatility. Benzene acts as a blood poison, lowering the count of red and white corpuscles and leading to hæmorrhage of the mucous membrane. The "fume process" regulations mention benzene and mixtures containing this hydrocarbon, but toluene and the higher homologues are not included.

The Applications of Petroleum Solvents.

The industrial applications to which petroleum solvents are put may conveniently be divided under three headings: (*a*) extraction processes in which the petroleum products are used as solvents for oils or fats; (*b*) deposition processes in which the petroleum products are used as thinners or diluents in solutions which give a film of rubber, cellulose, paint, etc., on drying; and (*c*) miscellaneous applications, in most of which the petroleum products are used as a source of light or heat.

(a) *Extraction Processes.*

(i) *Oil-seed Extraction.*

The oil from oil-bearing seeds, etc.—*e.g.*, cotton-seed, ground nut, and soya beans—can be removed from the ground product either by pressure or by extraction with a suitable solvent, which is subsequently recovered from the oil by distillation. Occasionally the two processes are com-

bined, the residue from the press, which still contains a proportion of oil, being extracted with solvent. The primary advantage offered by the solvent process is that practically the whole of the oil can be removed, the residual meal containing as little as 0·5 per cent. oil, as against anything between 5 per cent. and 10 per cent. in the case of a pressing plant. There was originally a certain amount of prejudice against the use of extracted oils for edible purposes, but it is now accepted that there is no difference in quality between oils extracted by the two methods. The extracted meals are utilized for feeding purposes or as manures, the extraction process being particularly suitable in the latter case because of the very small proportion of oil in the residual meal, so that extracted meals which cannot be used as cattle foods (castor, for example) make valuable fertilizers. In some cases extracted meals are mixed with a binding agent—*e.g.*, molasses—and compressed into cake nuts or feeding cakes.

The first stage of the extraction process is the breaking up of the oil cells so as to facilitate the action of the solvent, this being effected by some type of grinding machinery varying according to the nature of the seeds or nuts under treatment. Materials such as ground nuts, which require shelling before the grinding process, are first put through a "decorticating" machine. From the grinding house the ground material is passed by elevators and conveyors to bins situated over the extraction vessels, into which it is charged as required.

Solvent from the storage tank is run into the extraction vessel (sometimes warm solvent is used), and the mass is allowed to soak, after which the solution of oil in solvent is run off and the solvent recovered by evaporation and subsequent condensation. Usually a series of extraction vessels is used, arrangements being made so that the fresh seeds or beans are first treated with spirit which has already been used for two or three extractions (and consequently containing a certain amount of oil), whilst fresh spirit is used for the extraction of the seeds which have already been almost completely extracted by previous applications of spirit. By the adoption of this counter-current principle the amount of oil left in the residual meal is reduced to a minimum. The residue in the extractor, after draining to remove solvent, is steamed to remove the last traces of solvent, after which it is passed to the drying machine.

For seed extraction, particularly where the extracted oils are used for edible purposes, the solvent must be free from unsaturated hydrocarbons. A low aromatic content appears generally to be preferred, although solvents of aromatic content anywhere between, say, 5 per cent. and 50 per cent. by weight have been employed successfully in this country. The extraction solvent normally used for seed extraction is S.B.P. No. 2 spirit, although the heavier S.B.P. No. 5 spirit is also used for this purpose.

(ii) *Perfume Extraction.*

In perfume extraction the flower petals are mixed with the solvent in a closed apparatus, at ordinary temperatures, the solvent subsequently being separated by distillation, leaving the perfume wax as a residue. The extracted perfumes are chemically very unstable, particularly at high temperatures, and it is necessary to use a rather volatile solvent such as S.B.P. No. 2 spirit, free from sulphur and unsaturated hydrocarbons.

The extraction of 1 lb. of perfume wax involves the use of large quantities of solvent (100–400 gallons), and it is clear that even a minute percentage of odorous residue in the solvent will be a relatively large one in the perfume wax.

An interesting example of the extraction of essences from flowers is the treatment of pyrethrum flowers with a light-petroleum solvent for the extraction of the pyrethrins, which are used as the toxic principle in many insecticides, fly sprays, etc.

(iii) *Glue Manufacture.*

Bones and other animal refuse are the raw material used for the manufacture of animal glue, bone manures, and bone fertilizers. The bones are extracted in a suitable steam-heated extractor with a solvent, the grade normally used being S.B.P. No. 5 spirit. The solvent removes the oil and grease, the extract being run off and distilled with steam to yield fatty material, which is then distilled to give a white fatty acid used in candle manufacture. The extracted bones are treated in autoclaves at a pressure of 1½ atmospheres in the presence of steam to dissolve out the glue, the extract on concentration yielding animal glue. The residual bones are crushed to a fine powder, and are either sold as bone manure (bone meal) or treated with sulphuric acid for the manufacture of superphosphate.

In the extraction of bones it is essential to use a solvent with an end-point not exceeding, say, 105° C., since solvents of higher end-point tend to dehydrate the glue substance unduly, giving a product of inferior adhesive quality. On the other hand, the boiling point of the solvent must be sufficiently high to ensure that the bones are gradually dried during the extraction, so that the solvent may have a chance to extract the fats completely.

(iv) *Other Extraction Processes.*

Fish offal and waste food from restaurants are treated in drying plants to remove most of the water content and are then extracted with a solvent (usually S.B.P. No. 2 spirit or S.B.P. No. 5 spirit) to remove oil. The residue is worked up into fish-meals and poultry foods. It may be noted that where these feeding stuffs are sold for consumption by cattle or poultry the seller is required by the Fertilisers and Feeding Stuffs Act, 1926, to state the oil content of such products. The same requirement holds equally in the case of feeding cakes and meals intended for cattle and poultry and made from oil-seeds, *e.g.*, cotton-seed or linseed.

S.B.P. spirits (usually the No. 5 grade) are used for the extraction of grease from dried sewage sludge in certain centres of the textile industry where the extraction of grease is an economic proposition.

(v) *Dry Cleaning.*

In dry cleaning the soiled articles are treated in mechanical washers similar to those used in laundries, petroleum spirit being used instead of water. From the washer the articles are transferred to centrifugal extractors, where the spirit is separated and put back into circulation. The cleaned garments are dried in heated chambers and are finally pressed.

Various types of spirit are used in dry cleaning, many of the smaller concerns using Pool Rubber Solvent or even ordinary motor spirit for the purpose, although the shop-window type of cleaner uses, of course, a non-inflammable chlorinated solvent. The large dry cleaners use white spirit, which, unlike ordinary motor spirit, contains no volatile fractions which lead to excessive working losses and undue fire risks. Since its flash-point exceeds 73° F., white spirit comes outside the restrictions of the Petroleum Consolidation Act of 1928, so that a user does not have to conform with the somewhat irksome requirements of that Act.

The methods adopted for dry cleaning vary considerably, as do the methods by which clean spirit is regenerated from the dirty solvent. In some plants the clothes are placed in a tumbler, which consists of a perforated container (in which are the clothes to be cleaned) inside a fixed container. The perforated container is rotated, whilst clean solvent is fed in at the top of the machine and dirty solvent taken off at the bottom, to be circulated through the reclamation plant. In other plants which operate on a batch system there is no continuous flow of solvent through the tumbler, which means that the last of the dirt has to be removed by the dirtiest solvent and the clothes are removed from a dirty solvent.

Mechanically suspended impurities in the dirty solvent are removed by settling, or preferably a centrifuge, but this treatment does not remove dissolved impurities (mainly mineral oil or fatty oils and greases) or colouring matters. These can only be removed by distillation of the solvent or by treating the dirty solvent with a decolorizing powder.

It may be mentioned that treatment with white spirit (or with any other dry-cleaning liquid) will not remove spots caused by paint or varnish, ink, blood, etc., and it is frequently necessary to " spot " articles which have been dry cleaned, various types of " spot remover " being available according to the nature of the spot to be removed.

(vi) *Leather Processing.*

Rubber solutions or cements are used to stick together the various parts from which the uppers of boots or shoes are built up, immediately prior to stitching. It is essential that the cement should be made up with a volatile solvent, which dries very rapidly, and it is advisable to use a spirit of low aromatic content, because with this type the risk of staining due to penetration of the leather by the cement is minimized. This latter factor is naturally of particular importance in the case of fancy leathers. S.B.P. No. 1 spirit is normally employed in rubber cements.

Channel cements are used for sticking down the leather (which has been cut along a groove on the sole) to allow the sole stitching to be pulled home tightly. Here again a volatile solvent is required in the preparation of the cement.

Apart from their use in the boot and shoe industry, petroleum solvents are employed for degreasing purposes in the preliminary manufacture of the leather itself. Quite large quantities of kerosine are used for the degreasing of skins, particularly in the glove industry, the grade usually employed being Pool Vaporising Oil (*a*) because the solvent power for grease is higher than that of Pool Burning Oil and (*b*) because of its better volatility. The skins, after dehairing with milk of lime and sodium

sulphide, are rotated in a wooden tumbler with Pool Vaporizing Oil, sometimes with the addition of a little sulphonated oil, the amount of vaporizing oil used varying from ½ gallon to 1½ gallons per dozen skins, according to the size of skin and its fat content. After the treatment the vaporizing oil is run off and the skins are washed with two or three successive brine solutions to remove the remaining kerosine. Some manufacturers carry out the process at ordinary temperatures, others warm the kerosine up to 90° F., which naturally facilitates the extraction. If the fats and greases are not removed at this stage the finished skins, after dyeing, exhibit white patches or "spue" due to the separation of fatty material on the surface.

It may be appropriate to mention that most of the troubles attributed to the use of kerosine in leather degreasing have been shown to be due to the employment of an insufficient quantity of solvent.

Petroleum solvents are used in the cleaning of furs, their object being to act as wetting agents to facilitate combing of down from the furs before these are given a final sawdust treatment, which removes the residual spirit and gives a "polish" to the fur. Various solvents ranging from motor spirit to white spirit are being used for the purpose.

(b) *Deposition Processes.*

(i) *The Rubber Industry.*

Petroleum solvents are used in many different branches of the rubber industry. Large quantities are consumed by tyre manufacturers and by the proofing industry, and smaller, but appreciable, amounts by makers of adhesive tapes, surgical plasters, golf balls, tennis balls, rubber gloves, etc.

Petroleum solvents for the rubber-proofing and spreading industry should be free from very volatile fractions which enhance the fire risk and lead to excessive evaporation losses, and also free from very heavy or high-boiling fractions which cannot easily be removed from the finished goods. In consequence, Pool Rubber Solvent is usually employed in rubber-proofing and in the manufacture of waterproof garments, etc. Where the proofing machines work very rapidly, or the length of travel of the proofed cloth before being rolled is unduly short, a more volatile spirit may be used—*e.g.*, S.B.P. No. 5 or S.B.P. No. 2 grades.

Petroleum solvents have very largely replaced the coal-tar solvents which were formerly used for rubber-proofing. The advantages of the former are: (*a*) a more carefully controlled distillation range and evaporation rate; (*b*) absence of complex sulphur compounds and unsaturated bodies which might affect the ageing properties of the rubber; and (*c*) a lower degree of toxicity, a factor of importance in badly ventilated or congested workshops.

In the manufacture of proofed goods the rubber, intimately mixed with the various pigments, fillers, and accelerators, is masticated, and is incorporated with solvent to give a dough-like mass, which is then coated on to the fabric on steel rollers covered with a moderately hard rubber. The dough is scraped on to the cloth by means of a blade-like gauge while it passes over this roller. The proofed fabric passes over a steam-heated

chest, where the solvent is evaporated. Vulcanization is effected either by cold cure, with a solution of sulphur chloride in carbon disulphide, or by hot cure in stoves heated by steam-pipes. In the second case the mix used for proofing contains the necessary sulphur for vulcanization, but with cold cure vulcanization sulphur is omitted from the mix.

The more modern types of plant are equipped with hoods, through which the mixture of air and solvent vapour is drawn off and passed to a solvent recovery plant, usually of the "activated carbon" type.

The solvents used by the rubber-tyre industry before the war differed very considerably in properties, many buyers having their own purchasing specifications, especially in the case of concerns subsidiary to, or allied with, tyre manufacturers in the States or on the Continent. Most tyre-makers now use S.B.P. No. 4 spirit, although some use Pool Rubber Solvent or a narrow range product such as S.B.P. No. 3 spirit.

In the manufacture of tyres the first stage is the impregnation with rubber of the cord fabric. This may be done either by passing the cord fabric through a solution of rubber in a suitable solvent, or by what is known as frictioning on the calender, a process which eliminates the use of solvent altogether.

The rubber mix used for tyre manufacture is masticated with solvent and milled with the necessary fillers (zinc oxide, etc.), sulphur and organic accelerator (to reduce the time of vulcanization). The mix for impregnation of the cord fabric is white, but for subsequent coats on the fabric and for the tread and bead a black mix is used, the black colour being due to the incorporation of carbon black.

The tyre body is built up on a drum from successive layers of rubberized cord fabric, which are bedded down by special tools as the drum revolves. An application of petroleum spirit between the layers assists in the process of consolidation. The beads are bound into the side-walls with fabric, and the breaker strip and tread are then fitted.

The tyre is finally consolidated by vulcanization, this being done by the combined effects of heat and pressure under carefully controlled conditions. The tyre casing is placed in an iron mould, which is embossed internally with the tyre pattern to be transferred to the tread, and an air-bag similar to an inner tube is inserted, the air pressure forcing the tyre into close contact with the mould. The mould is then transferred to an autoclave for the vulcanization process.

In the manufacture of inner tubes the rubber mix is extruded from a machine in the form of a tube, coated with talc powder, and cut into suitable lengths. A hole is cut out for the valve, which is fitted loosely, and the ends are coated with rubber solution and stuck together. The tube is inflated and cured in an iron mould heated by superheated steam, this process fixing in the valve as well as completing the vulcanization.

Dipping processes are involved in the manufacture of toy balloons, surgical gloves, etc. The solution of rubber in a suitable solvent is made up, and a wood or porcelain model or "former," having the shape of the article required, is immersed in the solution, and then removed to allow the solvent to evaporate. By repeating the process several times a sufficient thickness of rubber is built up gradually, after which the article is vulcanized by treatment with a solution of sulphur chloride in a solvent (usually

carbon disulphide), and is finally stripped from the "former." Difficulties are occasionally encountered where the rubber solutions are made up with too volatile a solvent, or where atmospheric temperatures are unduly high, pinholes and blisters being produced, or water being deposited through the chilling resulting from the excessive evaporation rate, with a consequent development of a haze throughout the article.

The solvents used in dipping processes vary in volatility between S.B.P. No. 1 spirit and rubber solvent, according largely to the type of article manufactured.

In the manufacture of tennis balls segments are cut from sheets of suitable thickness, and before closing these together, by means of a solution of rubber in petroleum solvent, a suitable amount of inflating medium is inserted, the ball then being placed in a mould (made in two halves) for vulcanization. The heat of the curing process decomposes the inflating medium—*e.g.*, sodium nitrite and ammonium chloride which produce nitrogen gas—and gives the necessary inflation of the ball.

(ii) *Cellulose Lacquers.*

Nitrocellulose lacquers consist essentially of nitrocellulose dissolved in comparatively expensive organic solvents, together with resins, plasticizers and, in the case of coloured lacquers, pigments. The solvents can be divided into three general classes: the alcohols, esters, and ketones, and since no one solvent combines all the properties which are desirable, a mixture of solvents is employed.

In order to cut down production costs, it is customary to include in the lacquer formula a proportion of diluent, either of petroleum or coal-tar origin. These diluents are not true solvents, and the percentage employed is limited by this fact, since excess of diluent throws the nitrocellulose out of solution. For this reason the diluent must be so selected, both as regards quantity and quality, that it evaporates at the same rate as, or rather more rapidly than, the true solvents in the lacquer. If the diluent is too volatile, pinholes or blisters may be produced when the lacquer film dries, but if it is of too low volatility and evaporates more slowly than the true solvents, there will be an over-concentration of diluent in the film as it dries, and the nitrocellulose will be thrown out of solution, giving rise to what is known as "blushing."

For industrial purposes a rapid rate of drying is often essential, but the rate of drying is limited by the chilling effect due to evaporation. If this limit is passed, water is precipitated from the air, and what is known as "water blush" results.

It is usual to employ petroleum diluents of comparatively narrow distillation range, and, generally speaking, the higher the percentage of aromatics the greater is the proportion which can be included in a lacquer without precipitation of the nitrocellulose—*i.e.*, the greater is the "dilution ratio" of the product. S.B.P. No. 2, S.B.P. No. 3, and S.B.P. No. 6 grades, as well as Pool Rubber Solvent, are all used widely as lacquer diluents. These products correspond approximately in evaporation rate with coal-tar benzole, toluole, xylole, and solvent naphtha, respectively.

The proportion of petroleum diluent in a lacquer can frequently be increased by a modification of the formula used—*e.g.*, by increasing the

amount of butyl alcohol in the lacquer when this is used, by the replacement of butyl acetate by amyl acetate, or of ethyl acetate by cellosolve. It may be economical at times to use a more expensive solvent if it will allow more of the cheaper petroleum diluent to be incorporated without precipitation of the nitrocellulose.

A reference to the use of coal-tar benzole as a lacquer diluent is made in a later section of this paper.

(iii) *Printing Inks.*

The problems of the rotogravure ink industry are, in so far as the choice of a suitable petroleum diluent is concerned, very similar to those of a maker of cellulose lacquers. The essential properties are a satisfactory rate of evaporation and an aromatic content sufficiently high to avoid precipitation of such components of the ink as chlorinated rubber or some of the newer types of resins. Either S.B.P. No. 3 or Pool Rubber Solvent is normally used in printing inks, although some makers include S.B.P. No. 6 spirit in their formula. For really high-speed rotogravure printing (where 40,000 copies an hour may be produced, the paper travels at the rate of 1200 feet per minute, and the ink must dry off completely in a fraction of a second) a more volatile spirit—*e.g.*, S.B.P. No. 2 grade—is used.

Petroleum solvents (usually Pool Rubber Solvent) are also used in the printing-ink industry as "blanket washes" for cleaning ink from the rubber rollers of the printing machines.

(iv) *Paints, Varnishes, etc.*

Paints and varnishes provide the main outlet for Pool White Spirit, and this application of a petroleum product is so well known that any detailed references would probably be superfluous. Originally introduced as a cheap alternative to vegetable turpentine, white spirit was at first marketed under the name "turpentine substitute," but it has now proved itself the equal of turpentine for the great majority of paints used for household or industrial purposes. The main difference between white spirit and turpentine is the greater solvent power of the latter for certain resins and bodied vegetable oils, and this restricts the use of white spirit in some varnishes and enamels.

White spirit is used as a volatile thinner in many bitumen paints and in the compositions employed for printing the pattern on linoleum and oil-cloth.

Kerosine and Pool Distillate are often used in the manufacture of stove enamels and some of the cheaper types of paint.

(v) *Polishes.*

Another extensive outlet for white spirit is in the manufacture of polishes, of which there are three main types:

(*a*) Floor, leather, and shoe polishes.
(*b*) Emulsified polishes or creams.
(*c*) Abrasive polishes—*e.g.*, metal polishes.

Polishes of type (*a*) consist essentially of a blend of wax (or, more usually, a mixture of waxes) with white spirit, to which is often added a small proportion of turpentine to cater for the prejudices of the "old school." In their preparation the waxes are melted in a steam-jacketed pan and brought to a predetermined "thinning temperature," when the cold solvent is added to the melted wax, with constant stirring. The solvent is added at a rate such that when addition is complete the mixture has reached the so-called "filling temperature" (the optimum temperature for any particular formula), after which the thin paste produced is filled into tins and allowed to cool. The final appearance and consistency of the finished polish depend largely on the correct selection of the "filling temperature."

The emulsified polishes or creams are emulsions of wax in water, made up with an emulsifying agent, and often with the addition also of a proportion of white spirit. These emulsions are usually made in homogenizers or colloid mills, and it is claimed that when white spirit is included in the formula the resultant product is of a smoother consistency and will stand up better to storage conditions.

With the abrasive polishes dirt, stains, and oxidized films are removed by means of an abrasive, assisted by the solvent action of the water and the solvent (usually white spirit) present in the polish. By this means a completely fresh surface is exposed, which polishes on rubbing. Metal polish is a suspension of abrasive in water, the abrasive being thoroughly wetted with white spirit before it is added to the water. Since the abrasive is finely ground and is wetted with a liquid of lower specific gravity than water, this ensures that it will not sink to the bottom and form a paste.

(c) *Miscellaneous Applications.*

(i) *Alcohol Dehydration.*

Alcohol and water cannot be completely separated by distillation, and when, for example, an alcohol/water mixture obtained by the fermentation of molasses is distilled, the "rectified spirit" obtained consists approximately of 95½ per cent. alcohol 4½ per cent. water. This mixture boils at a lower temperature than the boiling points of either pure alcohol or pure water, and until comparatively recently the water content could not be reduced except by the use of chemicals—an expensive process.

Modern methods make use of azeotropic distillation for the production of anhydrous alcohol, and if benzene (C_6H_6) is added to the 95½ per cent. alcohol/water mixture, and the whole distilled, the first product to come over is a three-component mixture in the proportions of 74·1 per cent. benzene, 18·5 per cent. alcohol, 7·4 per cent. water, which boils at 64·85° C. This mixture has a much higher water/alcohol ratio than the original rectified spirit, so that as long as there is any water present (and sufficient benzene), this mixture distils over. In practice an excess of benzene is used, with the result that the residual liquid in the still is an alcohol/benzene blend, and this, when the temperature is increased to 68·2° C., gives a second constant-boiling mixture containing 67·6 per cent. benzene and 32·4 per cent. alcohol, which distils over to leave pure alcohol free from both water and benzene.

The three-component and two-component constant-boiling mixtures are

combined, cooled, and allowed to settle, when they separate into two layers, the upper layer, rich in benzene, being returned to the azeotropic distillation column. The lower layer of alcohol/water, but still containing

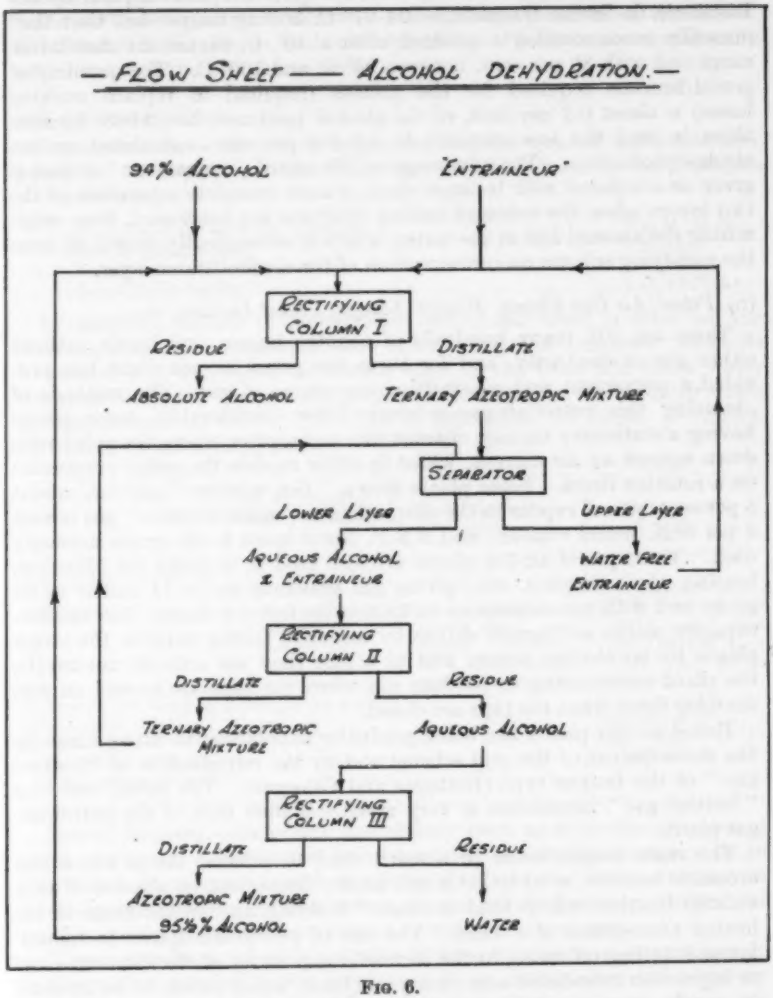


FIG. 6.

FLOW SHEET—ALCOHOL DEHYDRATION.

some benzene, is passed to a small still, where the benzene is removed, and it then goes to the first rectifying still to produce the 95½ per cent. alcohol which is fed to the azeotropic distillation plant. In practice the whole process is a continuous one (Fig. 6).

In the Melle process (Distillerie de Sèvres, Melle, France) a mixture of petroleum spirit and benzene is used as a separation agent (entraineur), in the ratio of 2 volumes benzene to 1 volume petroleum spirit. It is understood that a very narrow petroleum spirit cut was supplied by the Distillerie de Sèvres themselves—94–97° C. boiling range—but that they normally recommended a product with a 10° C. maximum distillation range and with 80 per cent. between 96° C. and 100° C. The quantity of petrol/benzene required for the process (required to replace working losses) is about 0·2 per cent. of the alcohol produced, but where benzene alone is used the loss amounts to 0·3–0·4 per cent. calculated on the alcohol production. The advantage of the mixed " entraineur " is that it gives, as compared with benzene alone, a more complete separation of the two layers when the constant-boiling mixtures are condensed, thus minimizing the amount lost in the water, which is subsequently drawn off from the rectifying column on concentration of the alcohol/water layer.

(ii) *Petrol/Air Gas Plants, Miners' Lamps, Pocket Lighters, etc.*

There are still many hundreds of country houses and hotels without either gas or electricity, and for them the petrol/air-gas plant has provided a convenient and relatively cheap source of gas. The methods of obtaining this petrol/air-gas mixture differ considerably, some plants having a stationary zig-zag, channel-like carburettor where the spirit runs down against an air current, whilst in other models the spirit evaporates on a rotating drum. Some plants give a " rich mixture " gas (*i.e.*, about 5 per cent. petrol vapour in the gas), others a " weak mixture " gas (about 2 per cent. petrol vapour), and S.B.P. No. 1 spirit is the grade normally used. These petrol/air-gas plants are also used in industry for soldering, brazing, cloth singeing, etc., giving gas pressures up to 14 inches water gauge and with gas outputs up to 3500 cubic feet per hour. The smaller-capacity plants are usually driven by means of falling weights, the larger plants by an electric motor, and as a rule they are entirely automatic, the plant commencing to produce gas when the taps are turned on and shutting down when the taps are closed.

Petrol/air-gas plants are being gradually supplanted in many areas by the development of the grid scheme and by the introduction of " bottled gas " of the butane type (Bottogas and Calorgas). The initial cost of a " bottled-gas " installation is very much less than that of the petrol/air-gas plant.

The main requirements of a spirit used in miners' lamps are a low aromatic content, so as to get a non-smoky flame, and an absence of very volatile fractions which tend to cause " building up " of the flame in the heated atmosphere of a mine. The use of petroleum spirits in miners' lamps is falling off owing to the increased popularity of electric lamps and to legislation introduced some few years back, which called for an increase in candle-power, an increase which could not be met by the spirit-type miners' lamps. Lamps of this type are, however, still used extensively for gas detection in mines. S.B.P. No. 4 spirit is the most widely employed grade, but recent experience suggests that less volatile grades are perhaps rather more suitable.

For petrol blowlamps and for incandescent mantle lamps either S.B.P.

No. 1 or S.B.P. No. 4 spirit is chiefly used, although in both cases ordinary motor spirit is often employed.

For petrol lighters a spirit of similar characteristics to that used in miners' lamps is required, S.B.P. No. 4 grade being normally employed. Some customers prefer a narrower-boiling-range product of the S.B.P. No. 2 or S.B.P. No. 3 type, and small quantities of perfume are occasionally added to mask the petroleum odour.

(iii) *Laboratory Uses.*

Petroleum ethers, of various types, are used for general analytical purposes, as, for example, in the following tests laid down by the Institute of Petroleum :—

Analysis of tar–bitumen mixtures	T.B.M. 26 (T.).
Dirt in paraffin scale	P.S. 14*a*.
Free alkali and acid in greases	L.G. 5.
Saponifiable matter	L.O. 15 (T.).

In addition, 60–80° C. sulphonated petroleum ether is used for the determination of asphaltenes and other analytical purposes (methods A. 12 and F.O. 12), water-estimation spirit in the Dean and Stark water determination, and sludge-testing spirit in the test for the sludging value of transformer oil (T.O. 21). The specifications for these petroleum solvents are summarized below :—

	60–80 Sulphonated petroleum ether.	Water-estimation spirit.	Sludge-testing spirit.
Spec. gravity at 60° F.	Not below 0·680. Not above 0·690.	—	Not above 0·700.
Distillation range.	At least 90% between 60° C. and 80° C.	5% temperature not below 90° C., not above 100° C. 90% temperature not above 205° C.	I.B.P. not below 60° C.—at least 75% at 100° C.—F.B.P. not above 120° C.
Aromatics (by weight).	Not above 0·5%	—	Not above 2%.
Iodine value (Hubl.).	—	—	Not above 0·3%.
Aniline point after treatment with 98–100% sulphuric acid.	—	—	Not above 58° C. (136° F.).

Solvent Recovery.—Reference has already been made to the recovery of used solvent by a distillation process, and it is scarcely necessary to go into details in connection with this form of solvent recovery. Distillation is the normal method of recovering solvent which has been utilized for what in this paper have been classed as extraction processes.

Where petroleum solvents are used in deposition processes, particularly in the rubber-proofing industry, the use of an activated-carbon recovery plant is now the rule, rather than the exception. In such plants the solvent-laden atmosphere is drawn off by means of fans through absorbers containing activated carbon, which takes up a certain quantity of the solvent, depending on (*a*) the absorbing power of the carbon, (*b*) the concentration of solvent in the mixed air/solvent vapour, and (*c*) the temperature of absorption. When the carbon in the absorber is nearly

saturated with solvent, the gases are diverted to a second container, and the solvent from the first absorber is recovered, usually by steaming, followed by condensation from the vapours. It is claimed that with petroleum solvents it is an economical proposition to recover solvent in a concentration as low as 1 part in 2000.

In the rubber-proofing industry the spreading machines are fitted with carefully designed hoods to collect the solvent vapour and prevent its diffusion into the room. These hoods do not come right down to the steam chests, and they allow a free current of air to be carried up into the hood, where it mixes with the solvent vapour, so as to bring the solvent concentration of the mixture below the lower explosive limit.

Figures quoted by the makers of these solvent-recovery plants show a recovery of 80 per cent. and over of the original spirit used, and it is within the authors' experience that recoveries of this order are obtained in practice by many users. Apart from the financial aspect, the recovery plant has been responsible for an appreciable reduction in the number of fires on the spreading machines and for an improved atmosphere in the spreading rooms.

Legislation—Safety Precautions, etc.—Special boiling-point spirits and rubber solvent are distributed either in bulk (rail car or road wagon) or in packages (barrels or cans), the method employed depending mainly on the quantities delivered and on the distance from the Petroleum Board's nearest bulk stocks. Deliveries in packages naturally involve a rather higher price than deliveries in bulk.

Where delivery is effected by rail car the usual quantity is of the order of 4000 gallons, but the maximum quantity which can be delivered by a road vehicle is 2500 gallons. The regulations covering road transport are laid down in the Petroleum Spirit (Conveyance) Regulations, 1939 (S.R. and O., 1939, No. 1209). Where deliveries are made in packages, these are normally either heavy steel, 50-gallon barrels or the usual type of 2-gallon petrol can.

The regulations dealing with the storage and use of " petroleum spirit "—*i.e.*, any petroleum product with a flash-point (Abel closed test) below 73° F.—are laid down in the Petroleum (Consolidation) Act, 1928. Petroleum spirit must not be kept without a licence unless (1) it is kept in separate glass, earthenware, or metal vessels, securely stoppered and containing not more than 1 pint each, and aggregating not more than 3 gallons, or (2) it is kept and used for motor vehicles, motor boats, etc., in accordance with the Petroleum Spirit (Motor Vehicles, etc.) Regulations, 1929. Storage licences are granted by the appropriate local authority—*i.e.*, the L.C.C. in London (except in the City) and the district council in other areas—and these local authorities may attach to a petroleum-spirit licence such conditions as they may think expedient. (At the present time additional restrictions may be imposed in some areas by the police or the military authorities.)

The Petroleum (Consolidation) Act, 1928, makes it obligatory for vessels containing petroleum spirit (unless the container is the fuel tank of a vehicle, etc.) to be labelled " Petroleum Spirit—Highly Inflammable," such containers to show the name and address of the owner, the sender or the vendor, as the case may be. A further requirement of the same

Act is that all accidents involving loss of life or personal injury by explosion or fire " in or about or in connection with " any premises licensed for petroleum spirit must be reported.

Among the processes certified by the Home Office as dangerous under certain sections of the Factory and Workshops Acts are the following, in which petroleum spirits may be employed :—

(1) Manufacture, use, and storage of cellulose solutions.
(2) Certain processes incidental to the manufacture of india-rubber.

The regulations dealing with cellulose solutions are contained in the Cellulose Solutions Regulations, 1934 (S.R. & O., 1934, No. 990), the regulations being amplified in a memorandum issued by the Home Office in 1936 (Form 826, April 1936). The definition of " cellulose solution " in the Regulations is " any solution in inflammable liquid of cellulose acetate, of cellulose nitrate, of celluloid, or of any other substance containing cellulose acetate, cellulose nitrate or any other cellulose compound, with or without the admixture of other substances." The definition of inflammable liquid includes any liquid or mixture of liquids with flash-point below 90° F., so that S.B.P. No. 6 spirit comes within the scope of the Cellulose Solutions Regulations, 1934, although it is outside the scope of the Petroleum (Consolidation) Act, 1928.

Where benzene is used as a component of cellulose solutions, the Regulations insist on certain additional precautions being taken, including the special labelling of receptacles containing cellulose solutions or inflammable liquids in which the benzene content exceeds 15 per cent. by weight. The S.B.P. spirits and rubber solvent all contain very much less than 15 per cent. benzene.

The India rubber Regulations, 1922 (S.R. & O., 1922, No. 329), define a " fume process " as " any process in which any of the following materials :— carbon bi-sulphide (CS_2), chloride of sulphur (S_2Cl_2), benzene (C_6H_6), whether pure or in the form of commercial benzol, carbon tetrachloride (CCl_4), trichlorethylene (C_2HCl_3), or any carbon chlorine compound, or any mixture containing any of such materials is used, or the vapour of any such materials is given off." Ordinarily, no person under 18 years of age must be employed in any fume process (and no person under 16 years of age in any room in which a fume process is carried on), and special regulations apply in connection with medical examination, ventilation, etc.

All petroleum solvents with fractions boiling below, say, 90° C. contain benzene (C_6H_6) to a greater or less extent, and consequently they come, strictly speaking, within the " fume process " regulations. In practice it is usual for the regulations to be waived where the benzene content is not above 5 per cent. by weight. Reference to the table given earlier in this paper will show that the *total* content of aromatic hydrocarbons in the grades likely to contain benzene does not exceed the 5 per cent. limit mentioned.

Other memoranda issued by the Home Office, and of interest to users of petroleum solvents, are the following :—

Memorandum on Dry Cleaning (Form 824, July 1924).
Prevention of Dermatitis (Form 1863, April 1928).

Prevention of Oil Rashes (Form 296, February 1932).

Precautionary Notes for users of volatile organic solvents (Form 297, June 1937).

Memorandum on the cleaning or repairing of oil and acid stills and tanks in factories (Form 814, January 1930).

In conclusion, the authors would express their thanks to the Management Committee of the Petroleum Board for permission to publish this paper, to Mr. G. L. Coles for helpful criticism and suggestions, and to Mr. W. A. Woodrow for determination of some of the data presented.

THE INSTITUTE OF PETROLEUM.

A MEETING of the Institute of Petroleum was held at The Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W. 1, on Tuesday, 10th June, 1941, with the President (Professor A. W. Nash) in the chair.

The PRESIDENT said that the authors of the paper to be read that evening were both well known to the members of the Institute. Mr. Harrap was an authority on special products from petroleum, and contributed a paper on "Dangerous Gases and Products" in 1939, and Dr. Evans was a member of the Institute Council, and was known for his able work on viscosity and other physical properties. Both gentlemen were now engaged on important tasks with the Petroleum Board, and the Institute was extremely grateful to them for finding the time to put together such a useful and appropriate paper in the present circumstances. It was no light task to compile a scientific paper under the strain of war-time conditions, and he would like to express the Institute's thanks to the authors for their work.

The following paper was then read by the authors:

"Hydrocarbon Solvents from Petroleum and their Industrial Applications." By F. N. Harrap, M.Sc., and Dr. E. B. Evans (see page 369).

DISCUSSION.

DR. R. LESSING, in proposing a vote of thanks to the authors, said he did so with sincerity, because this was the type of paper of which the authors could be proud. Although the paper did not put forward any new theories or discoveries, it added to their knowledge, and although the branch of the industry dealing with the production of solvents was quantitatively a minor one compared with the large bulk of products from the other crude oil, he thought it was a most interesting one. The larger branches were in certain respects, if he might say so, of less interest, because the only object of producing perfectly good and useful hydrocarbons was to subject them to complete destruction by one or another method of combustion.

Most of those present probably knew a good deal about solvents, being connected with the production side. Even to them it formed a welcome compilation of facts and figures. But the paper should appeal particularly to the large body of consumers in the chemical and allied industries in which solvents were applied in a variety of processes. He would go so far as to suggest (he did not know whether he was in order) that it might be a useful function of the Institute, in a case such as the present, to make papers available to a wider circle than the Fellows and Members of the Institute itself. Was there any procedure by which it could be published in booklet form for the benefit of those who were users of solvents and were very frequently at a loss to know what to order or to ask for? The question of trying to marry requirements and available supplies was most urgent, particularly at the present time.

Extraction processes were coming more and more into use, employing, of course, not only hydrocarbons, but also what might be termed chemical solvents. It was a useful thing to have the various types which were available, and their properties, made known under war conditions.

One point which had been touched upon was the chemical composition of the solvents, the amount of aromatics, naphthenes, and so on, not only from the point of view of Home Office requirements, but in respect of their behaviour towards the materials to be extracted under various conditions. This was of great importance, and raised the question of the chemical compounds in petroleum which he felt sure would eventually be one of the major problems for the research workers in the oil industry.

He had great pleasure in proposing a vote of thanks to Mr. Harrap and Dr. Evans.

Dr. D. A. Howes seconded the vote of thanks. The authors had spoken with real authority, and members could take anything they said as being correct. The paper was a very able summary of an extremely complicated subject, and he would like to see it followed up by a series of papers dealing in greater detail with the various aspects of solvents and their applications because, as Dr. Lessing had mentioned, the manufacture and use of solvents constituted a most important subject.

The President put the vote of thanks to the meeting, and it was carried with acclamation.

Dr. D. A. Howes said there was one question he would like to ask. The authors had given the properties of a range of petroleum solvents; was he correct in assuming that these were all self-consistent—in other words, that they applied to a series of solvents in present-day use produced from a particular crude oil, or group of crude oils processed in a particular fashion, but that the solvent properties might be considerably modified by a change in the crude source or conditions of manufacture? As the solvents described are mostly paraffin in character, what would be the effect of producing them from a predominantly naphthenic or aromatic crude oil?

Mr. A. J. Goodfellow said that the authors had gone into some detail in describing specifications of the S.B.P. grades, but no mention had been made of bromine and iodine values. What was the significance of the specified values which the Pool gave to the grades? There was another point which was outside the scope of the paper, but could a rough outline of the manufacture and uses of petroleum sulphonates be given?

Mr. F. L. Bassett said that the manufacture of "cut-back" bitumens might be regarded as an example of the use of solvents more or less in the kerosine or gas-oil range, and when working on this subject in Iraq he had not been able to obtain much information on the specification of the distillates to be used for fluxing road bitumen, other than the general descriptions such as "heavy" or "light" kerosine, etc. The set-up of cold mixed bituminous road surfaces depended on several factors apart from the composition of the binder, but from the standpoint of the local manufacturer of cut-back or fluxed bitumen it was desirable to have a fairly definite specification of the solvent oil, as well as of the bitumen.

Dr. Evans said that the authors would like to express their thanks to the President, Dr. Lessing, and Dr. Howes, for their kind remarks. It had been a pleasure to prepare and present this review of the war-time position of petroleum solvents in this country, and they hoped also that the paper contained information which would be of more permanent interest to those concerned with solvents.

Replying to Dr. Howes, Dr. Evans said that actually the solvent properties described in the paper applied more particularly to those spirits the properties of which were given in Tables II and III. They had indicated in the introductory paragraphs that certain high solvency materials, of a very aromatic nature, which were available before the war, were no longer available, and he thought it could be taken for granted that during the course of the war the material available would continue to be very much of the type of the solvents described in the paper. A check-up from such easily determined features as the gravity would indicate any marked variation. The authors felt that the spirits which had been described were typical of those which were likely to be available for some time to come. Incidentally, they were very similar to one class of solvents available before the war. Certain high-solvency products available before the war were no longer obtainable. Spirits derived from crudes containing higher proportions of naphthenes or, particularly, aromatics would have, in general, higher solvencies, which would render them more suitable for some applications.

In reply to Mr. Goodfellow, Dr. Evans said that the low bromine values which were sometimes quoted were to ensure the almost complete absence of unsaturated hydro-

carbons. If he looked at Table XIII he would notice that the unsaturateds were only in the neighbourhood of ½ per cent., and were getting near to the figure where it was difficult to measure the presence of unsaturateds with any degree of accuracy. Bromine or iodine values in the neighbourhood of 3 or 5 indicated a straight-run product. S.B.P.'s, which had been refined more than ordinary straight-run products, would normally have considerably smaller values than 3 or 5. There was also the possibility of substitution, and that might account for a small value being obtained.

With regard to sulphonates, this was rather outside the scope of the present paper, and he was sorry he could not give offhand any information on that point.

The same remarks applied to the question of fluxes for cutback manufacture, raised by another speaker. The authors' activities had changed considerably since the war, and they were not in a position to discuss the situation as it existed at present.

The PRESIDENT said that he could not contribute anything of value to the discussion because it was outside his sphere of work. They were very grateful to the authors for a paper which introduced a certain amount of the practical side, in which some of the papers of the past had been a little deficient, and enabled those who worked on the theoretical side to appreciate some of the problems and applications of those things with which they were continually experimenting.

One point which arose in his mind was that before the war representatives of petrol companies were saying that their petrol had "something which the others had not got," but petrol had now been reduced to one common brand and the industrial solvents to a mere handful.

The meeting then concluded.

EXPANSION OF CRUDE PETROLEUM, PETROLEUM PRODUCTS AND ALLIED SUBSTANCES

*Report of Institute of Petroleum Sub-Committee J, Sampling and Measurement.**

SUB-COMMITTEE J, Sampling and Measurement, was appointed to deal with questions relating to the measurement of oil in bulk. The expansion of petroleum, petroleum products and allied substances is an important factor to be taken into consideration when dealing with such questions. The sub-committee therefore made arrangements to collect information on this subject, and as a result data were obtained for 179 materials. The object of the report is to present this information in a form which it is hoped will be useful to the petroleum industry.

The expansion data supplied were in a variety of forms, *e.g.*, coefficients of cubical expansion, change in density per degree Centigrade change in temperature, change in reading of a glass specific gravity hydrometer in the liquid with change of temperature, etc. This was a natural and anticipated result of asking members of the sub-committee and others to supply any data available to them. It was considered preferable to adopt this procedure and undertake the work of reducing the data to a common basis, rather than to issue a rigid questionnaire asking for data in a prescribed form which would probably have resulted in much less information being obtained.

In view of the position outlined in the preceding paragraph, it was necessary for the committee to adopt a common basis to which to reduce the information available. It was decided to determine for each material.

(*a*) Its specific gravity $S_{60^\circ F./60^\circ F.}$ defined by the relation

$$S_{60^\circ F./60^\circ F.} = \frac{\text{Density of material at } 60^\circ \text{ F.}}{\text{Density of water at } 60^\circ \text{ F.}} \quad . \quad . \quad . \quad (1)$$

in which density is mass per unit volume.

(*b*) The value of B for the material, where B is defined by the relation

$$S_{t^\circ F./60^\circ F.} = S_{60^\circ F./60^\circ F.} + B(60 - t) \quad . \quad . \quad . \quad . \quad (2)$$

where $S_{t^\circ F./60^\circ F.}$ is the specific gravity of the material at t° F. defined by the relation

$$S_{t^\circ F./60^\circ F.} = \frac{\text{Density of material at } t^\circ \text{ F.}}{\text{Density of water at } 60^\circ \text{ F.}} \quad . \quad . \quad . \quad (3)$$

It was found that to the degree of accuracy required in commercial transactions the linear relation (2) is adequate.

In addition to determining $S_{60^\circ F./60^\circ F.}$ and B for each material, it was considered desirable to have some standard of reference with which these values could be compared. Consequently, values of B were deduced

* Mr. Verney Stott was responsible for the collection and presentation of the data, and the Sub-Committee wish to record their thanks to him for the considerable work involved.

from Table 3 of the "National Standard Petroleum Oil Tables" (U.S. Bureau of Standards Circular C 410 : 1936) for the whole range of specific gravity covered by this table. These values are designated by B_s throughout this report, and values of B calculated for individual materials are designated by B_c. Comparison between the value of B_c for a given material and the corresponding value of B_s, *i.e.*, the value of B_s for the same specific gravity $S_{60°F./60°F.}$ as that of the material, not only gives a useful basis of comparison, but also the magnitude of the difference serves to determine over what temperature range, to the degree of accuracy required in any particular operation, the tables in C 410 may safely be used for the material.

Values of B_s derived from Table III of C 410 are given in Table I.* It is

TABLE I.

Values of B_s *derived from Circular* C 410.

Specific gravity $S_{60°F./60°F.}$	$B_s \times 10^5$.	Specific gravity $S_{60°F./60°F.}$	$B_s \times 10^5$.
0·622–0·631	55	0·743–0·755	45
0·632–0·641	54	0·756–0·766	44
0·642–0·651	53	0·767–0·777	43
0·652–0·663	52	0·778–0·788	42
0·664–0·676	51	0·789–0·801	41
0·677–0·688	50	0·802–0·813	40
0·689–0·702	49	0·814–0·832	39
0·703–0·717	48	0·833–0·865	38
0·718–0·730	47	0·866–0·960	37
0·731–0·742	46	0·961–1·000	36

stated in Circular C 410 that the tables are based largely on an investigation of American petroleum oils published in "Density and Thermal Expansion of American Petroleum Oils" by H. W. Bearce and E. L. Peffer (Technologic Paper No. 77 of the National Bureau of Standards, 1916). This paper gives the density at various temperatures of eighty seven different oils, and from the data given values of $S_{60°F./60°F.}$ and B_c have been calculated for each individual oil. It is of interest to compare these values with corresponding values of B_s obtained from Table I. The comparison serves to indicate how closely values of B_s derived from Table III of C 410 agree with the values of B_c for the individual oils on the properties of which the tables in C 410 were based. This comparison is given in Tables II and III, which, in addition to values of B_c and B_s and the differences B_c–B_s, give also the number of density determinations on which each value of B_c is based and the range of temperature covered by these determinations.

In Table II are listed, in order of increasing specific gravity, all the oils for which B_c–B_s is within the range $\pm$0·00003. For such oils the use of Table III of C 410 to obtain the specific gravity $S_{60°F./60°F.}$ of an oil would give a result over a range of temperature of 30° F. differing by less than

* The coefficient of cubical expansion of glass is not involved in the definition of B_s given in equation 2 but is involved in Table 3 of C 410; due allowance was made for this when computing values of B_s as defined by equation 2 from Table 3 of C 410.

TABLE II.

American Oils from N.B.S. Technologic Paper No. 77 having Values of $B_e - B_s$ *within the Range* ± 0.00003.

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F./60°F.}$	Value of $B_e \times 10^5$	Corresponding value of $B_s \times 10^5$ derived from Table 3 of C 410.	Difference $(B_e - B_s) \times 10^5$
1	*a*	2	32–77	Refined oil, pentane.	0·623	57	55	+2
2	*a*	2	32–77	Refined oil, pentane.	0·626	54	55	−1
3	*a*	2	32–77	Refined oil, pentane.	0·642	54	53	+1
4	*a*	2	32–77	Refined oil, pentane.	0·642	53	53	0
5	*a*	7	32–122	Naphtha.	0·687	49	50	−1
6	*a*	7	32–122	Gasoline.	0·707	49	48	+1
7	*a*	7	32–122	Naphtha.	0·711	47	48	−1
8	*a*	7	32–122	Gasoline, Texas.	0·738	47	46	+1
9	*a*	7	32–122	Gasoline, Pennsylvania.	0·740	46	46	0
10	*a*	7	32–122	Gasoline (treated), California.	0·741	48	46	+2
11	*a*	7	32–122	Gasoline (treated), California.	0·752	46	45	+1
12	*a*	7	32–122	Naphtha, Indiana.	0·754	46	45	+1
13	*a*	7	32–122	Engine distillate, California.	0·776	44	43	+1
14	*a*	7	32–122	Gasoline, Oklahoma.	0·784	42	42	0
15	*a*	7	32–122	Kerosine, Pennsylvania.	0·788	41	42	−1
16	*a*	7	32–122	Kerosine, Pennsylvania.	0·789	41	41	0
17	*a*	7	32–122	Kerosine, Pennsylvania.	0·789	41	41	0
18	*a*	7	32–122	Lighthouse oil, Louisiana.	0·791	41	41	0
19	*a*	7	32–122	Kerosine, Pennsylvania.	0·794	40	41	−1
20	*a*	7	32–122	Kerosine, Pennsylvania.	0·795	40	41	−1
21	*a*	7	32–122	Kerosine, Ohio.	0·799	41	41	0
22	*a*	7	32–122	Kerosine, Indiana refined.	0·802	41	40	+1
23	*a*	7	32–122	Kerosine, Oklahoma.	0·803	41	40	+1
24	*a*	7	32–122	Kerosine, Mid-Continent.	0·807	41	40	+1
25	*a*	7	32–122	Kerosine, California.	0·814	41	39	+2

24	*a*	7	32–122	Kerosine, Mid-Continent.	0·807	41	40	+1
25	*a*	7	32–122	Kerosine, California.	0·814	41	39	+2
26	*a*	3	32–122	Crude oil, Pennsylvania.	0·815	40	39	+1
27	*a*	7	32–122	Kerosine, California.	0·819	41	39	+2
28	*a*	3	32–122	Crude oil, Louisiana.	0·820	41	39	+2
29	*a*	3	32–122	Burning oil (High F.T.).	0·829	37	39	−2
30	*a*	7	32–122	Refined oil, Louisiana Mineral Seal.	0·829	37	39	−2
31	*a*	3	32–122	Crude oil, Texas.	0·832	39	39	0
32	*a*	3	32–122	Crude oil, Pennsylvania.	0·833	39	38	+1
33	*a*	3	32–122	Crude oil, Louisiana.	0·843	36	38	−2
34	*a*	7	32–122	Refined oil, Pennsylvania.	0·848	37	38	−1
35	*a*	7	32–122	Refined oil, Indiana.	0·852	38	38	0
36	*a*	3	32–122	Crude oil, Ohio.	0·854	40	38	+2
37	*a*	3	32–122	Refined oil, neutral.	0·855	37	38	−1
38	*a*	3	32–122	Refined oil, neutral.	0·862	36	38	−2
39	*a*	2	32–77	Crude oil, Mid-Continent.	0·863	37	38	−1
40	*a*	7	32–122	Refined oil, California. Stove oil (treated).	0·866	39	37	+2
41	*a*	6	50–122	Refined oil, Pennsylvania.	0·868	36	37	−1
42	*a*	4	77–203	Autocylinder	0·869	35	37	−2
43	*a*	3	32–122	Crude oil, Oklahoma.	0·871	39	37	+2
44	*a*	7	32–122	Dynamo oil, Pennsylvania.	0·871	36	37	−1
45	*a*	7	32–122	Refined oil, Pennsylvania.	0·871	36	37	−1
46	*a*	4	77–203	Fuel oil.	0·871	38	37	+1
47	*a*	4	77–203	Autocylinder.	0·872	35	37	−2
48	*a*	3	32–122	Refined oil, Louisiana.	0·874	37	37	0
49	*a*	3	32–122	Refined oil, Louisiana, neutral.	0·874	36	37	−1
50	*a*	7	32–122	Refined oil, Pennsylvania.	0·875	34	37	−3
51	*a*	4	77–203	Fuel oil.	0·879	37	37	0
52	*a*	3	32–122	Marine engine oil.	0·884	37	37	0
53	*a*	4	77–203	Gas engine oil.	0·887	34	37	−3
54	*a*	3	32–122	Gas engine oil.	0·888	36	37	−1
55	*a*	3	32–122	Refined oil, Louisiana.	0·891	37	37	0
56	*a*	3	32–122	Crude oil, California.	0·898	39	37	+2
57	*a*	7	32–122	Refined oil, Indiana.	0·902	36	37	−1
58	*a*	3	32–122	Paraffin oil.	0·902	37	37	0

TABLE II—*continued.*

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F./60°F.}$	Value of $B_e \times 10^6$	Corresponding value of $B_e \times 10^6$ derived from Table 3 of C 410.	Difference $(B_e - B_s) \times 10^6$
59	*a*	7	32–122	Engine oil.	0·903	37	37	0
60	*a*	3	32–122	Cylinder oil.	0·905	38	37	+1
61	*a*	3	32–122	Crude oil, California.	0·907	37	37	0
62	*a*	4	77–203	Locomotive oil.	0·907	36	37	−1
63	*a*	4	77–203	Non-condensing cylinder oil.	0·907	36	37	−1
64	*a*	3	32–122	Crude oil, Louisiana.	0·910	38	37	+1
65	*a*	3	32–122	Paraffin oil.	0·911	37	37	0
66	*a*	3	32–122	Crude oil, Texas.	0·914	37	37	0
67	*a*	3	32–122	Cylinder oil.	0·917	40	37	+3
68	*a*	4	77–203	Locomotive oil.	0·921	36	37	−1
69	*a*	4	77–203	Marine-engine oil.	0·924	36	37	−1
70	*a*	3	32–122	Crude oil, California.	0·926	39	37	+2
71	*a*	4	77–203	Gas-engine oil.	0·927	36	37	−1
72	*a*	4	77–203	Gas-engine oil.	0·927	36	37	−1
73	*a*	2	86–104	Crude oil, Texas.	0·929	39	37	+2
74	*a*	7	32–122	Refined oil, Texas.	0·929	37	37	0
75	*a*	2	86–104	Crude oil, Texas.	0·930	37	37	0
76	*a*	4	77–203	Stationary-engine oil.	0·935	35	37	−2
77	*a*	3	32–122	Gas-engine oil.	0·938	36	37	−1
78	*a*	2	86–104	Crude oil, Texas.	0·940	37	37	0
79	*a*	3	32–122	Refined oil, Texas.	0·941	36	37	−1
80	*a*	4	77–203	Marine-engine oil.	0·946	36	37	−1
81	*a*	3	32–122	Refined oil, Texas.	0·946	36	37	−1
82	*a*	2	86–104	Crude oil, Texas.	0·950	38	37	+1
83	*a*	4	77–203	Fuel oil.	0·960	37	37	0
84	*a*	4	77–203	Fuel oil.	0·961	36	36	0
85	*a*	2	86–104	Crude oil, California.	0·967	37	36	+1

TABLE III.

TABLE III.

American Oils from N.B.S. Technologic Paper No. 77 having Values of $B_c - B_s$ *outside the Range* $\pm 0{\cdot}00003$.

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F./60°F.}$	Value of $B_c \times 10^5$	Corresponding value of $B_s \times 10^5$ derived from Table 3 of C 410.	Difference $(B_c - B_s) \times 10^5$
86	*a*	3	32–122	Cylinder oil.	0·900	42	37	+5
87	*a*	3	32–122	Refined oil, Indiana.	0·931	41	37	+4

TABLE IV.

Materials for which Data were supplied to the Committee having Values of $B_c - B_s$ *within the Range* $\pm 0{\cdot}00003$.

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F./60°F.}$	Value of $B_c \times 10^5$	Corresponding value of $B_s \times 10^5$ derived from Table 3 of C 410.	Difference $(B_c - B_s) \times 10^5$
88	*h*	—	55–65	Spirit.	0·660	49	52	−3
89	*b*	—	—	American petroleum.	0·662	52	52	0
90	*b*	—	—	Gasoline, Persian.	0·662	52	52	0
91	*i*	—	32–86	Gasoline, Iraq S.R.	0·667	53	51	+2
92	*c*	—	62–92	Benzine, light, Rumanian.	0·682	52	50	+2
93	*i*	—	32–86	Gasoline, *iso*Octane.	0·702	46	48	−2
94	*d*	—	68–86	Gasoline, light crude.	0·703	49	48	+1

TABLE IV—*continued.*

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F./60°F.}$	Value of $B_e \times 10^5$	Corresponding value of $B_t \times 10^5$ derived from Table 3 of C 410.	Difference $(B_e - B_t) \times 10^5$
95	*b*	—	—	Aviation spirit.	0·707	48	48	0
96	*c*	—	63–92	Spirit. Distillation range 0–109° C.	0·708	51	48	+3
97	*c*	—	61–92	Spirit. Distillation range 0–124° C.	0·715	48	48	0
98	*g*	3	56–85	Benzine, Iranian B.	0·724	45	47	−2
99	*g*	7	52–76	Benzine, Iranian B.	0·725	44	47	−3
100	*d*	—	68–86	Export gasoline.	0·725	48	47	+1
101	*b*	—	—	Benzine.	0·726	47	47	0
102	*g*	8	53–80	Benzine, light, Rumanian.	0·726	49	47	+2
103	*h*	—	55–65	Spirit.	0·744	47	45	+2
104	*h*	—	55–65	Spirit.	0·751	47	45	+2
105	*c*	—	60–92	Spirit. Distillation range 124–148° C.	0·751	48	45	+3
106	*g*	2	54–82	Blend : 20% Aviation Benzol and 80% Iranian Benzine B.	0·753	47	45	+2
107	*c*	—	62–92	Raw benzine.	0·754	47	45	+2
108	*h*	—	55–65	Spirit.	0·754	47	45	+2
109	*g*	4	52–75	Blend : Ethyl Alcohol and Iranian Benzine B.	0·757	46	44	+2
110	*c*	—	60–92	Spirit. Distillation range 148–164° C.	0·760	45	44	+1
111	*c*	—	57–63	Benzine, heavy.	0·772	43	43	0
112	*d*	—	—	Spirit. Distillation range 164–178° C.	0·773	44	43	+1
113	*b*	—	—	White spirit.	0·779	43	42	+1
114	*b*	—	—	Kerosine (SO_2 refined).	0·782	39	42	−3
115	*d*	—	68–86	Export gasoline.	0·784	42	42	0
116	*c*	—	—	Spirit. Distillation range 178–200° C.	0·788	44	41	+3
117	*b*	—	—	Kerosine.	0·790	42	41	+1

118	c	—	—	Distillation range 160–178° C.	0·795	42	41	+1
119	i	—	32–86	Gasoline, British Borneo.	0·799	44	41	+3
120	c	—	60–92	Distillation range 200–220° C.	0·802	43	40	+3
121	i	—	32–86	Kerosine, Iranian.	0·802	41	40	+1
122	b	—	—	L.T. B.O.	0·804	40	40	0
123	c	—	68–92	Kerosine, Rumanian. Campeni Bacau.	0·804	42	40	+2
124	c	—	61–92	Kerosine, Rumanian. Glodeni.	0·804	38	40	−2
125	c	—	—	Raw product. Tatcani-Antal. P. Gercatura.	0·805	38	40	−2
126	c	—	—	Kerosine, Rumanian. Policiori.	0·806	42	40	+2
127	c	—	68–92	Kerosine, Rumanian. St. Romana.	0·808	43	40	+3
128	c	—	—	Spirit. Distillation range 178–195° C.	0·810	42	40	+2
129	c	—	61–92	Kerosine, Rumanian. Policiori.	0·811	38	40	−2
130	c	—	—	Raw product. Marita-Ochisor. P. No. 4.	0·811	42	40	+2
131	c	—	61–92	Kerosine, Rumanian. Campina.	0·812	39	40	−1
132	c	—	62–63	Kerosine.	0·812	41	40	+1
133	i	—	32–86	Kerosine, Venezuelan.	0·813	42	40	+2
134	c	—	58–92	Spirit. Distillation range 220–238° C.	0·814	39	39	0
135	c	—	—	Raw product. Campeni Bacau S. No. 1.	0·814	42	39	+3
136	i	—	32–86	Kerosine, Borneo (Edeleanu-treated).	0·815	41	39	+2
137	i	—	32–86	Kerosine, Trinidad (Edeleanu-treated).	0·816	41	39	+2
138	c	—	58–92	Spirit. Distillation range 238–252° C.	0·823	38	39	−1
139	c	—	68–92	Kerosine, Rumanian. Bustenari.	0·826	42	39	+3
140	c	—	64–92	Spirit. Distillation range 195–215° C.	0·826	42	39	+3
141	c	—	61–92	Kerosine, Rumanian. Moreni.	0·827	40	39	+1
142	c	—	—	Crude product. Baicoi S. No. 1.	0·831	40	39	+1
143	c	—	—	Crude product. Policiori P. No. 4.	0·834	39	38	+1
144	c	—	—	Crude product. Bustenari Faget S. No. 1.	0·834	41	38	+3
145	c	—	58–92	Spirit. Distillation range 252–270° C.	0·834	38	38	0
146	c	—	—	Crude product. Berca S. No. 3.	0·837	39	38	+1
147	c	—	—	Crude product. Campina S. No. 58.	0·838	38	38	0
148	b	—	—	Crude product, Persian.	0·840	40	38	+2
149	c	—	—	Crude product. Campina S. No. 1.	0·842	39	38	+1
150	i	—	60–113	Gas oil, Rumanian waxy.	0·843	38	38	0
151	c	—	—	Crude product. Glodeni P. No. 1.	0·843	38	38	0
152	c	—	58–92	Spirit. Distillation range 270–290° C.	0·843	37	38	−1

TABLE IV—*continued.*

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F/60°F}$.	Value of $B_s \times 10^5$	Corresponding value of $B_s \times 10^5$ derived from Table 3 of C 410.	Difference $(B_s - B_t) \times 10^5$
153	*e*	3	68–176	Transformer oil, No. 1.	0·845	37	38	−1
154	*c*	—	58–92	Spirit. Distillation range 290–311° C.	0·850	36	38	−2
155	*e*	3	68–176	Transformer oil, No. 2.	0·852	36	38	−2
156	*c*	—	—	Crude oil. Bustenari S. No. 44.	0·854	39	38	+1
157	*e*	—	50–158	Shale oil.	0·857	37	38	−1
158	*c*	—	—	Crude oil. Colibasi P. No. 36.	0·861	39	38	+1
159	*c*	—	59–64	Gas oil.	0·861	38	38	0
160	*c*	—	63–91	Distillation range 311–329° C.	0·862	39	38	+1
161	*g*	4	55–123	Transformer oil.	0·863	36	38	−2
162	*d*	—	68–86	Gas oil.	0·863	39	38	+1
163	*b*	—	—	Gas oil.	0·865	38	38	0
164	*c*	—	63–91	Distillation range 329–344° C.	0·865	39	37	+2
165	*e*	—	50–158	Refined machine oil.	0·867	35	37	−2
166	*c*	—	—	Crude oil. Lucacesti. P. Schinoasa.	0·872	38	37	+1
167	*e*	3	68–176	Transformer oil, No. 1.	0·876	36	37	−1
168	*c*	—	64–91	Distillation range 344–363° C.	0·876	39	37	+2
169	*c*	—	100–118	Distillate at 363° C.	0·881	37	37	0
170	*c*	—	—	Crude oil. Gura Ochetei S. No. 9.	0·888	39	37	+2
171	*c*	—	—	Crude oil. Sarata-Monteoru P. No. 3.	0·892	39	37	+2
172	*e*	—	50–158	Fuel oil.	0·893	37	37	0
173	*i*	—	32–86	Gas oil. Rumanian asphaltic.	0·893	39	37	+2
174	*b*	—	—	Fuel oil.	0·895	37	37	0
175	*c*	—	—	Crude oil. Moinesti. P. Sigmunda.	0·895	38	37	+1
176	*c*	—	61–90	Distillate at 340° C.	0·896	37	37	0
177	*e*	—	50–158	Refined spindle oil.	0·900	35	37	−2
178	*c*	—	61–92	Distillation range 340–343° C.	0·900	37	37	0
179	*c*	—	—	Crude oil. Bustenari S. No. 43.	0·902	39	37	+2

178	*c*	—	61–92	Distillation range 340–343° C.	0·900	37	37	0
179	*c*	—	63–92	Distillation range 286–304° C.	0·902	39	37	+2
180	*c*	—	64–91	Distillation range 340–343° C.	0·904	37	37	0
181	*i*	3	113–167	Venezuelan waxy distillate.	0·905	34	37	−3
182	*c*	—	63–92	Distillation range 304–321° C.	0·908	37	37	0
183	*c*	—	—	Crude oil. Tintea S. No. 7.	0·910	37	37	0
184	*c*	—	63–92	Distillation range 321–339° C.	0·910	37	37	0
185	*c*	—	64–92	Distillation range 339–340° C.	0·910	38	37	+1
186	*e*	—	50–158	Engine oil (refined).	0·910	34	37	−3
187	*i*	—	32–86	Borneo solar oil.	0·913	39	37	+2
188	*e*	—	50–158	Olive oil.	0·917	37	37	0
189	*b*	—	—	Lubricating oil.	0·918	35	37	−2
190	*c*	—	111–129	Lubricating oil, vacuum extra.	0·923	34	37	−3
191	*c*	—	129–167	Lubricating oil, vacuum extra.	0·923	36	37	−1
192	*c*	—	212–254	Lubricating oil, vacuum extra.	0·923	36	37	−1
193	*g*	4	58–123	Venezuelan cylinder oil (edeleanised).	0·923	34	37	−3
194	*d*	—	68–86	Crude oil, Potrero.	0·925	39	37	+2
195	*c*	—	90–97	Vacuum extra heavy.	0·930	35	37	−2
196	*d*	—	68–86	Light fuel oil.	0·934	38	37	+1
197	*e*	—	50–158	Fuel oil.	0·935	36	37	−1
198	*c*	—	57–92	Vacuum ideal.	0·935	36	37	−1
199	*c*	—	77–86	Lubricating oil.	0·942	36	37	−1
200	*i*	3	32–86	California (Lab. No. 42,884).	0·942	39	37	+2
201	*i*	2	58–124	Straight-run, Miri.	0·944	37	37	0
202	*g*	4	58–124	Fuel oil, Borneo.	0·944	37	37	0
203	*g*	—	59–124	Furnace oil, Iranian.	0·945	38	37	+1
204	*c*	—	71–95	Residue.	0·950	36	37	−1
205	*c*	—	95–135	Residue.	0·950	36	37	−1
206	*c*	—	100–196	Residue.	0·950	36	37	−1
207	*d*	—	68–86	Heavy fuel oil.	0·951	39	37	+2
208	*e*	—	50–158	Fuel oil.	0·954	36	37	−1
209	*g*	—	59–124	Fuel oil, Mexican.	0·965	36	36	0
210	*d*	—	68–86	Evaporated crude oil.	0·968	39	36	+3
211	*g*	4	55–121	Fuel oil (asphaltic), Venezuelan.	0·972	35	36	−1
212	*i*	3	32–86	Venezuelan (Lab. No. 42,885).	0·980	36	36	0
213	*i*	4	50–131	Cut-back asphaltic bitumen.	0·983	34	36	−2

TABLE V.

Materials for which Data were supplied to the Committee having Values of $B_c - B_t$ *outside the Range* $\pm 0{\cdot}00003$ *but within the Range* $\pm 0{\cdot}00005$.

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F./60°F.}$	Value of $B_t \times 10^5$	Corresponding value of $B_c \times 10^5$ derived from Table 3 of C 410.	Difference $(B_c - B_t) \times 10^5$
214	*i*	—	32–86	Gasoline, Iraq acid-treated, cracked.	0·709	52	48	+4
215	*i*	—	32–86	Gasoline, Iraq acid-treated, cracked.	0·711	52	48	+4
216	*i*	—	32–86	Gasoline, Trinidad.	0·727	51	47	+4
217	*i*	—	32–86	Gasoline, Rumanian.	0·731	50	46	+4
218	*c*	—	—	Spirit. Distillation range 109–124° C.	0·744	49	45	+4
219	*h*	—	55–65	Spirit.	0·750	49	45	+4
220	*c*	—	63–92	Spirit. Distillation range 124–148° C.	0·767	48	43	+5
221	*c*	—	63–92	Spirit. Distillation range 142–160° C.	0·782	46	42	+4
222	*i*	—	32–86	Gasoline, Iraq acid-treated. Reformed, redistilled.	0·791	46	41	+5
223	*i*	—	32–86	Gasoline, Iraq acid-treated. Reformed, as received.	0·792	46	41	+5
224	*c*	—	68–92	Kerosine, Rumanian. "Vega."	0·819	44	39	+5
225	*i*	—	32–86	Kerosine, Trinidad.	0·823	43	39	+4
226	*c*	—	68–92	Kerosine, Rumanian. Gura Ochitei.	0·830	43	39	+4
227	*i*	—	32–86	Kerosine, British Borneo.	0·838	42	38	+4
228	*i*	—	32–86	Kerosine, Borneo untreated.	0·845	42	38	+4
229	*c*	—	63–92	Spirit. Distillation range 215–237° C.	0·848	42	38	+4
230	*i*	—	32–86	Residue from re-distillation of a mixture of cracked and reformed Iraq benzines.	0·862	42	38	+4
231	*i*	—	32–86	Kerosine, Borneo (Edeleanu extract).	0·863	43	38	+5
232	*c*	—	63–92	Distillation range 237–262° C.	0·868	41	37	+4
233	*c*	—	—	Crude oil. Moreni S. No. 14.	0·869	41	37	+4
234	*c*	—	63–92	Distillation range 262–286° C.	0·887	42	37	+5
235	*g*	6	58–123	Fuel oil (paraffinous), Iranian.	0·921	42	37	+5
236	*i*	3	59–123	Straight-run, Southern.	0·921	42	37	+5
237	*i*	3	113–167	Sumatra.	0·925	33	37	−4
238	*i*	—	32–86	Residue from reforming Iraq benzine.	0·931	41	37	+4

237	*i*	3	113–167	Sumatra.	0·921	42	37	+5
238	*i*	—	32–86	Residue from reforming Iraq benzine.	0·925	33	37	−4
					0·931	41	37	+4

TABLE VI.

Materials for which Data were supplied to the Committee having Values of $B_c - B_s$ *outside the Range* $\pm 0{\cdot}00005$.

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°F./60°F.}$	Value of $B_c \times 10^5$	Corresponding value of $B_s \times 10^5$ derived from Table 3 of C 410.	Difference $(B_c - B_s) \times 10^5$
239	*c*	—	62–92	Benzine, heavy Rumanian.	0·714	42	48	− 6
240	*i*	—	32–86	Gasoline, Borneo straight-run.	0·789	49	41	+ 8
241	*g*	8	52–88	Benzine, Borneo.	0·789	48	41	+ 7
242	*g*	5	52–86	Blend, ethyl alcohol and Borneo benzine.	0·790	48	41	+ 7
243	*g*	4	32–86	Ethyl alcohol (100% EtOH).	0·794	47	41	+ 6
244	*g*	4	32–86	Ethyl alcohol–water mixture (95% EtOH by mass).	0·809	48	40	+ 8
245	*c*	—	124–160	Kerosine, Rumanian. "Vega."	0·819	45	39	+ 6
246	*c*	—	154–203	Kerosine, Rumanian. "Vega."	0·819	46	39	+ 7
247	*k*	3	32–104	*m*-Xylene.	0·869	47	37	+10
248	*k*	3	32–104	Toluene.	0·871	52	37	+15
249	*g*	7	51–87	Aviation benzol.	0·876	54	37	+17
250	*k*	—	32–86	Benzole.	0·881	57	37	+20
251	*g*	5	49–86	Pure crystallisable benzene.	0·883	60	37	+23
252	*k*	3	32–104	Benzene.	0·884	59	37	+22
253	*i*	3	77–131	Sumatra (Lab. No. 42,886).	0·983	45	36	+ 9

TABLE VII.

Values of B_c for Asphaltic and Bituminous Materials.

Ref. No.	Ref. to source of data.	Number of density values given in original data.	Temperature range covered by original data, ° F.	Material.	Specific gravity $S_{60°\,F./60°\,F.}$	Value of $B_c \times 10^5$
254	*h*	—	70–320	Bitumen.	1·013	37
255	*f*	18	59–378	Asphalt.	1·016	31
256	*j*	—	60–275	Bitumen, Venezuelan. Pen. 180/200.	1·020	34
257	*i*	—	50–104	Asphaltic bitumen, Venezuelan. Pen. 80/100.	1·022	33
258	*f*	18	59–353	Asphalt.	1·024	32
259	*i*	3	50–104	Asphaltic bitumen, Egyptian. Pen. 80/100.	1·026	43
260	*f*	18	59–367	Asphalt.	1·028	32
261	*j*	—	60–275	Bitumen, Venezuelan. Pen. 41/50.	1·034	36
262	*f*	18	59–372	Asphalt.	1·042	33
263	*f*	18	59–367	Asphalt.	1·044	32
264	*g*	4	57–120	Edelenau extract.	1·045	37
265	*f*	18	59–378	Asphalt.	1·059	33
266	*j*	—	60–275	Bitumen, Panuco. Pen. 10/15.	1·078	34

TABLE VIII.

Frequencies of Values of $B_c - B_s$.

Value of $(B_c - B_s) \times 10^5$.	American petroleum oils of N.B.S. Technologic Paper No. 77.			*Materials listed in Tables IV–VI.		
	Number of materials having value of $B_c - B_s$ given in column A.	Percentage of materials having value of $B_c - B_s$ given in column A.	Percentage of materials having value of $B_c - B_s$ within the range ±0·00003.	Number of materials having value of $B_c - B_s$ given in column A.	Percentage of materials having value of $B_c - B_s$ given in column A.	Percentage of materials having value of $B_c - B_s$ within the range ±0·00003.
A.	B.	C.	D.	E.	F.	G.
+9	0	0		1	1	
+8	0	0		2	1	
+7	0	0		3	2	
+6	0	0		2	1	
+5	1	1		8	5	
+4	1	1		16	10	
+3	2	2		11	7	
+2	10	12		27	17	
+1	15	17		23	14	
0	24	28	98	29	18	78
−1	25	29		16	10	
−2	7	8		13	8	
−3	2	2		7	4	
−4	0	0		1	1	
−5	0	0		0	0	
−6	0	0		1	1	
−7	0	0		0	0	
−8	0	0		0	0	
−9	0	0		0	0	
Total	87	—	—	160	—	—

0·0010 from that given by the use of the value of B_c applicable to the particular oil. In Table III are similarly listed the oils of Technologic Paper No. 77 for which the value of B_c–B_s is outside the range ±0·00003. Of the eighty seven oils for which data are given in Technologic Paper No. 77, eighty five fall into Table II, and only two into Table III, and these two are recorded in the original paper as being oils probably containing solid particles at low temperatures.

There is therefore very close agreement between the values of B_c for the individual oils and the corresponding values of B_s obtained from Table I.

A similar comparison is made in Tables IV to VII between values of B_c for individual materials for which data were supplied to the committee and the corresponding values of B_s from Table I.

In Table IV are listed materials for which the values of B_c–B_s fall within the same range as in Table II, viz., ±0·00003, and 126 out of the 179 materials for which data were supplied to the committee come within this table.

The materials, twenty five in number, for which B_c–B_s is outside the range ±0·00003 but within the range ±0·00005 are listed in Table V. For these materials the use of B_s instead of B_c for reducing specific gravities $S_{t°\,F./60°\,F.}$ to $S_{60°\,F./60°\,F.}$ would result in errors exceeding 0·0010 but not exceeding 0·0015 when $t°$ F. differs from 60° F. by 30° F.

Tables IV and V together account for 151 out of the 179 materials for which data were supplied. The remaining twenty eight materials are accounted for in Tables VI and VII. Table VI includes fifteen materials for which B_c–B_s is outside the range ±0·00005. This table includes data for materials such as ethyl alcohol and toluene, which, though of interest to petroleum technologists, are materials which would not be expected to fall into line with ordinary petroleum oils.

Table VII includes thirteen asphaltic and bituminous materials having specific gravities $S_{60°\,F./60°\,F.}$ greater than 1·000. No values of B_s are available for specific gravities $S_{60°\,F./60°\,F.}$ greater than 1·000, but it is interesting to note that eleven out of the thirteen materials listed in Table VII have values of B_c within the range ±0·00004 of the value 0·00036 for B_s valid for $S_{60°F./60°F.} = 1·000$.

A rapid survey of the comparisons of B_c and B_s given in Tables II to VI inclusive may be obtained from Table VIII. In the first half of this table the number of the American petroleum oils of Technologic Paper No. 77 which have values of B_c–B_s given in column *A* of the table are given in column *B*, and the corresponding percentages of the total number of oils are given in column *C*. The second half of the table summarizes similarly the frequency of each value of B_c–B_s for the materials listed in Tables IV to VI, but six liquids of Table VI having values of B_c–B_s greater than 0·00009 have been omitted because they are special liquids, *e.g.*, pure crystallizable benzene.

The percentage of the American petroleum oils of Technologic Paper No. 77 which have values of B_c–B_s within the range ±0·00003 is very high, being 98 per cent., and this was to be anticipated, as these are the oils from which the values of B_s were derived. It is perhaps also of physical significance in that it may imply relative uniformity in the types of American petroleum from which the data for C 410 were obtained. Nevertheless,

whilst the percentage of materials from Tables IV to VI having values of B_c–B_t within the range $\pm$0·00003 is not so high as for the oils of Technologic Paper No. 77, it is still quite high—namely 78 per cent.—and shows that values of B_t derived from Table III of C 410 are applicable to a large number of the materials for which data were supplied to the committee.

Conclusions.

It cannot be claimed that the data collected are completely representative of all modern petroleum oils and petroleum products. Nevertheless, the data given in Table IV indicate that the "National Standard Petroleum Oil Tables" (U.S. Bureau of Standards Circular C 410 : 1936) are applicable to the degree of accuracy required in commercial transactions, to a large number of materials in addition to the American oils on which the construction of the tables of C 410 was based. It is hoped that Tables IV to VI will be useful when a decision has to be made, with regard to any particular product, whether the tables of C 410 may safely be used for the material, or whether it is necessary to use expansion data determined for the material itself.

The data collected may be taken as corroborating the wide applicability of the tables of C 410, and also as indicating their limitations. It is considered that an attempt to provide tables on the lines of those in C 140, which would be more widely applicable than those tables, would not be justifiable, as the work involved would be very great, and the resulting tables would not be capable of sufficiently more general use to justify the work. The best practical policy is to use the tables of C 410 wherever this is justifiable, and to use appropriate expansion data for such materials as differ from those on which C 410 is based so much as not to warrant the use of C 410.

Sources of Data.

a. "Density and Thermal Expansion of American Petroleum Oils" by H. W. Bearce and E. L. Peffer, National Bureau of Standards Technological Paper No. 77, 1916.
b. Dr. F. B. Thole.
c. Steaua Romana S.A.
d. Mr. McConnell Sanders.
e. The National Physical Laboratory.
f. Asphalt Laboratory, Monheim.
g. Mr. H. Hyams.
h. Mr. W. J. Jelffs.
i. Shell Refining and Marketing Co., Ltd., Central Laboratories.
j. Dr. F. H. Garner.
k. International Critical Tables.

OBITUARY.

WILLIAM MACNAB.

William Macnab died at Cookham Dene on 2nd September, in his 84th year. Educated at Greenock Academy and the Edinburgh Institution, he later studied chemistry and allied sciences at Glasgow University and Anderson's College. In his early career he specialized in sugar chemistry, holding first a post as analyst in a sugar refinery at Magdeburg and later one as chief chemist to the Clyde Wharf Sugar Refinery in London. Then for a few years during his connection with the Water Softening Company he was concerned with chemical and engineering problems, and installed plants in Canada and the United States. About 1897 he entered into a consulting partnership with C. Napier Hake, which practice he carried on alone after the latter had left this country for Australia. This work led to his association with mining, metallurgy, and the explosives industry, with which his name is chiefly connected. Before 1914 he was one of the recognized leading authorities on explosives, and during the last war was a member of Lord Moulton's Committee on Explosives, and Technical Adviser to the Ministry of Munitions. He was selected by the Government to compile "Technical Records of Explosives Supply, 1915–1919," being intimately connected with the design and erection of many of the large explosive works built at that time.

William Macnab was prominently connected with many scientific societies, and his association with this Institute goes back to 1913. In the first *Journal of the Institution of Petroleum Technologists*, as it was then, he is described as a "member who agreed to become such prior to the Foundation," and was thus connected with the earliest aims of Sir Boverton Redwood in its foundation. He continued his association with the Institute up to 1940, and was elected a Fellow in 1938.